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Metals and Alloys

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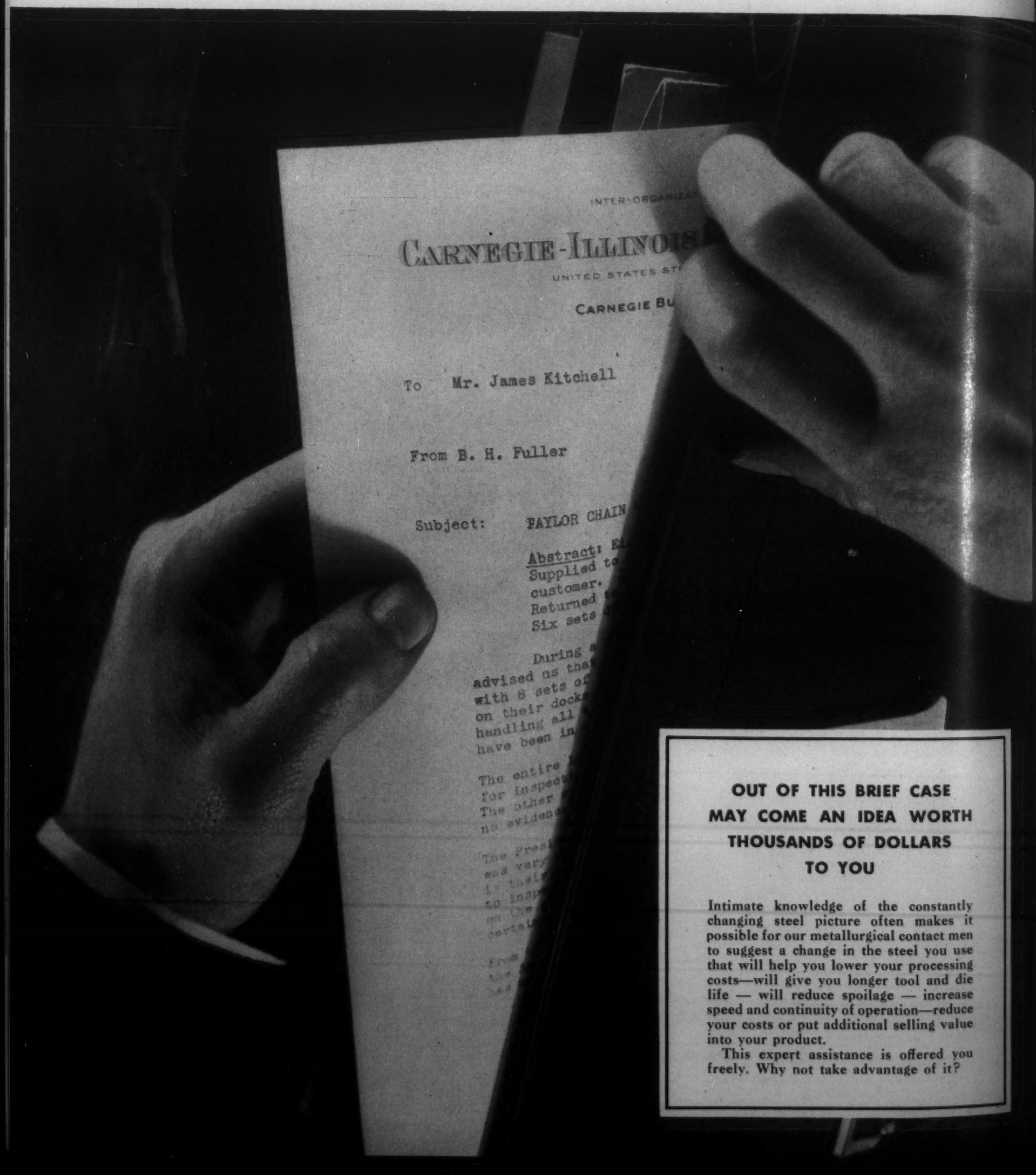
The *"best"* steel you


CARNEGIE-ILLINOIS
To Mr. James Kitchell
From B. H. Fuller
Subject: FAYLOR CHAIN
OUT OF THIS BRIEF CASE
MAY COME AN IDEA WORTH
THOUSANDS OF DOLLARS
TO YOU
Intimate knowledge of the constantly changing steel picture often makes it possible for our metallurgical contact men to suggest a change in the steel you use that will help you lower your processing costs—will give you longer tool and die life — will reduce spoilage — increase speed and continuity of operation—reduce your costs or put additional selling value into your product.
This expert assistance is offered you freely. Why not take advantage of it?

The General Practitioner

In earlier days there was a group of American metallurgists who could discuss practically any branch of metallurgy in truly illuminating fashion, men with great breadth of interests and equal breadth of vision. For example, recall Howe, Sauveur, Burgess, William Campbell, and Spring. Some such are still with us, e.g., Jeffries, Merica, Hoyt. None of these was ever afflicted with a single track mind, nor did he ever become so preoccupied with a little corner as to forget to swing his gaze over the whole metallurgical field.

We could name a good many younger men whose ability and whose early signs of breadth of vision fitted them to aspire to similar places in a metallurgical Hall of Fame, but who have limited their later interests to a much more specialized field. We think of individuals as experts in wrought copper base alloys, in cast iron, in stainless steels, in the application of one or another alloying element, in atomic structure of metals, in corrosion, in tonnage wrought steel, in constructional alloy steels, or in various other specific topics. The exigencies of their jobs usually appear to require great concentration and the process of concentration becomes one of exclusion. If one taxed these individuals with over-specialization, they would retort that they won't be a Jack of all trades and a master of none, or that a superficial academic smattering that might allow a professor to get by, won't serve in dealing with highly specific problems.

Admittedly, there is need for the specialist, but it seems to us that there is also need for the metallurgical engineer without any qualifying adjectives, just as there is need in medicine for the general practitioner. There is danger in having your medical problem handled by a specialist in ingrowing toenails or even a heart specialist when you've actually been bitten by a rattlesnake. The metallurgical analogies will suggest themselves.

It should be possible for a young metallurgist who is forced to specialize, to do so without closing his mind to the broader aspects of metallurgy, since it is primarily one's own attitude that controls the scope of the general principles and specific information he accumulates. Or, to put it another way, if the specialist keeps in mind the possibility of another and better job in some other field of metallurgy and seeks to be prepared to talk intelligently about the problems of the new job when he is interviewed for it, he is more likely to get that job and to make good in it after he gets it, than if he has sloughed off all other interests in the process of specialization.

It would be a pity if the new crop of metallurgical engineers should be too closely in-bred. There is little in-breeding in college, the courses will automatically be broad enough to serve as a foundation for most any type of job. Upon this the man must build his own superstructure, and he can choose how he will fashion it. Narrow specialization may serve if his job is always going to be a narrow one, but adoption of a broad range of interests might develop him into another Jeffries, and metallurgy could use more of that type.—H. W. G.

Open-Hearth Conferences

Attendance this year at the annual conference of the open-hearth and blast furnace committees of the A.I.M.E. left one with the definite impression not only of the earnestness of the members, but of the complexity of the problems involved and discussed.

When the open-hearth conference was instituted over 20 years ago, the problems, both metallurgical and mechanical, were simple as compared with those of today. As these problems have expanded, the growth of the conference has kept pace, so that this year's assemblage totaled over 500, the largest in its history. The topics discussed now include industrial relations, refractories, operations, metallurgy and so on. The complex labor laws and relations of today have intensified interest in the first of these, higher temperatures and operating conditions demand the best in refractories, automatic mechanical and other control by instrumentation have introduced new problems in operations, and the intensified requirements for physical and other qualities have made the work of the metallurgical engineer still more important.

An observer at this last meeting could not help but be particularly impressed with the unanimity of

(*Continued on page 196*)

Flood-Lubricated Sleeve Bearings for

Few precision bearings are required to take as much punishment as those on the necks of rolling mills. Rolling pressures are made as high as bearings and necks can stand, and often powerful impact loading is superimposed on this continuous heavy pressure. Modern finishing strip mills run at extremely high speeds, an added burden on the already heavily-taxed bearings. And all the time the bearings are pushed and pounded, they must hold to dimensions and maintain roll alignment without interfering with uninterrupted mill operation.

For many years the mill operators struggled protestingly along with the old open, grease-lubricated plain metal roll-neck bearing, because nothing better was available. Today this bearing is rapidly being replaced by roller bearings, lignum-vitae bearings, resinized bearings and by a modern sleeve bearing of unusual design and operating characteristics. This article describes the last—the "Morgoil" flood-lubricated sleeve bearing—with particular attention to the metals of which it is made, and to its serviceability in modern rolling mill applications.—The Editors.

BY FRED P. PETERS

Assistant Editor, METALS AND ALLOYS

Fig. 1. Sleeve Journal for a 56-in. Back-up Roll, Showing Typical Mirror Finish. The Morgoil bearing in which this sleeve is used has a continuous full-load capacity of 5,250,000 lbs.

Rolling Mills

"AS THE ROLL-NECK BEARING goes, so goes the mill" is a lot closer to the truth than the one about Maine and the Nation. Consider the expanding use of the 4-high mill and the steady increase in the number of continuous high speed strip mills in operation during the last 10 or 15 years. None of this would have been possible but for the timely development and application to this service of the roller bearing. True, the wide application of the anti-friction bearing depended on the use of mills with back-up rolls, with their generous differential between neck and barrel diameters, but the present-day industrial position of such mills could never have been attained if only the old plain metal grease-lubricated bearing were available. Why then, should anyone be interested in still another type of bearing? Hasn't the roller bearing completely solved the problem?

Today no problem can be considered completely solved so long as ingenuity and resourcefulness can freely devise and improve. The flood-lubricated sleeve bearing described in this article is as great an improvement over the plain-metal bearing as was the roller bearing, and in addition offers certain design and operating advantages not possessed by the anti-friction bearing. These may be somewhat clarified by a brief review of roll-neck bearings used during the last three decades.

The Simplest Bearing

Simplest in design, though not in performance, is the familiar, open, grease-lubricated, plain metal bearing, sometimes known as the "barnyard" bearing. Probably employed on the first rolling mill ever built, this type has continued in use to the present day, despite remarkable improvements both in rolling mill machinery and bearings in general. The shell of the conventional plain bearing is semi-circular in section, with a flare-out along its open length large enough to allow the roller to smear lubricant between the bearing surface and the roll-neck with a stick. The bearing metal is usually babbitted bronze or brass, and solid grease (often suet) is ordinarily used as the lubricant. Before the mill is started, the operator pokes a gob of grease into the opening between the bearing surfaces, and the grease works itself along the bearing after the mill runs a while and the grease thaws out.

In this starting-up period lubrication is very poor, the bearings heat irregularly, expand on one side more than the other, and the roller is continually forced to make roll adjustments. Tests have shown a coefficient of friction as high as 0.16 during the starting-up period, and 0.08 after the mill has been running some time. Wear is very heavy and it has been estimated on some mills that 50 per cent of the total power input is lost because of this factor alone, in the barnyard bearing. Bearing life is low and operation anything but uninterrupted. The open construction of this type of bearing is also a serious disadvantage, for grit and roll-cooling water carrying pieces of hard scale are splashed into the grease-feed opening between the bearing surfaces, to the obvious detriment of the latter.

The Roller Bearing

The roller bearing, first commercially applied to roll-necks around 1920, offered positive freedom from all these disadvantages and annoyances. The roller bearing is entirely enclosed and, although considerable attention must be paid to its lubrication, the problem is decidedly less annoying than with the barnyard bearing. Tests and actual application have shown tremendous power savings and improvement in durability for the roller bearing as compared with the older type. The operating advantages of tapered roller bearings have been discussed by Weckstein,[1, 2] who points out the additional advantages of (1) indefinite maintenance of alignment and accurate roll-setting because of negligible wear, and (2) their thrust-carrying ability, which makes unnecessary the use of special thrust bearings. Palmgren[3] has described the application of spherical roller bearings to rolling mill service, particularly hot mills, and cites the achievement of important power savings.

The roller bearing, however, is not perfect. Probably its greatest disadvantage is the extra space required for the bearing, which means that on 2-high mills particularly, the roll-neck diameter must be reduced to accommodate a roller bearing of sufficient capacity, with a consequent reduction in strength. On hot mills, where alloy iron rolls are often used in place of the much stronger forged steel rolls because of the tendency of the latter to firecrack, roll-neck diameter cannot be casually sacrificed. Also—as Dahlstrom[4] has pointed out—because the effective capacity of a roller bearing decreases with increase in speed, the size of the finishing stands of large strip mills must be increased to make room for roller bearings of sufficient capacity. This "extra size" means larger rolls, bigger housings and more weight generally, with attendant increase in operating, maintenance and overhead costs. Other drawbacks, some of them corollary to the foregoing, that have been cited[5] include the necessity to use more expensive roll materials, and the inconvenience sometimes experienced in changing rolls that have roller bearings on the necks. Roller bearings are also subject to a peculiar type of "compressive fatigue" resulting from the high unit stresses

associated with the alternating pressure and release of pressure of rollers against the race.

Non-Metallic Bearings

Lignum-vitae (hardwood) water lubricated bearings have also been used for roll-neck service. Atwater[6] mentions 23 per cent power-saving as compared with the barnyard bearing, and states that lignum-vitae bearings are less expensive, both to buy and to operate, than roller bearings. When really wet, the lignum-vitae bearings are unquestionably an improvement over the old plain metal bearings, but their superiority with respect to roller bearings is highly debatable. One discusser of Atwater's paper, for example, had made a comparative study of lignum-vitae and anti-friction bearings and had found both operating cost and durability to be better with the latter.

Much more widely used than the lignum-vitae bearing is another type—the resinized, or impregnated-fabric bearing, consisting of sheets of woven fabric, impregnated with phenolic resin and compressed at a high temperature into a hard, tough material. The advantages and applications of the various American proprietary products of this nature have been completely set forth elsewhere;[7, 8, 9, 10] also, in the recent British Symposium on Lubrication[11] several interesting comparisons of the composition bearing with the conventional plain metal bearing were reported. There seems to be general agreement that, even when water-lubricated, the fabric bearing is incomparably superior to the conventional plain metal bearing with respect to power savings and bearing life. Again, however, there is no definite evidence as yet that the fabric bearing can match the performance of the roller bearing in roll-neck service, although recently two important applications of composition bearings to back-up rolls were made—one on the broad siding stand of an 80-in. hot strip mill, the other on a 4-high Steckel hot mill.[17]

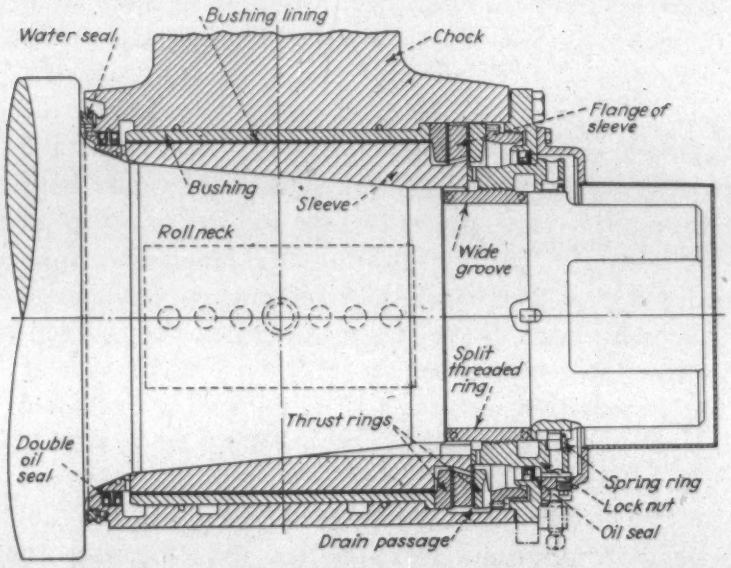


Fig. 2. Diagram of the Morgoil Bearing, Showing Essential Features.

The Morgoil Bearing

The "Morgoil" bearing, developed by the Morgan Construction Co., Worcester, Mass., after their unsatisfactory experience with roller bearings on the

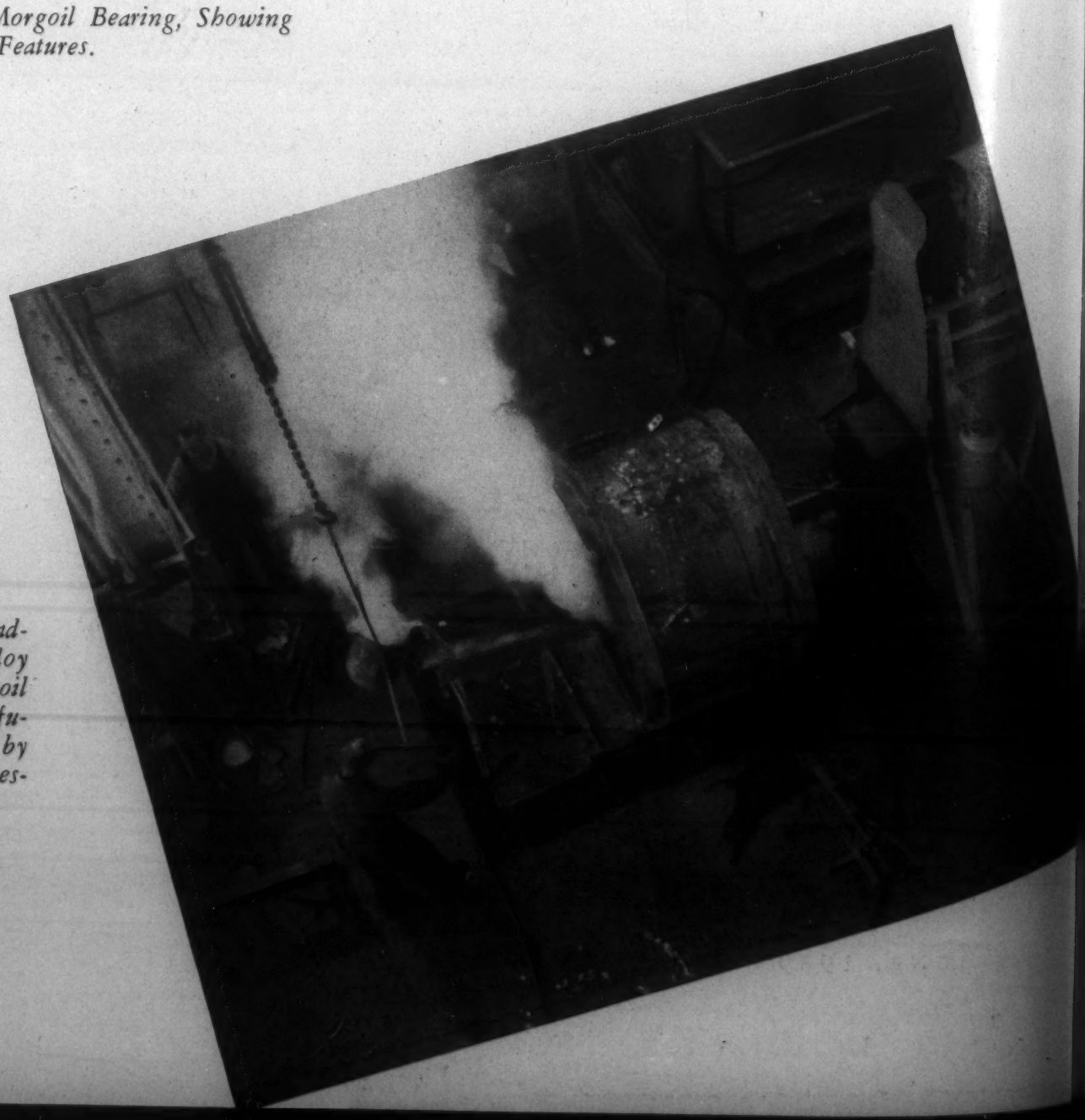


Fig. 3. Pouring Molten Cadmium-nickel Bearing Alloy into the Bushing of a Morgoil Bearing in a Special Centrifugal Casting Machine Built by Morgan. (Courtesy: Worcester Sunday Telegram)

necks of 2-high hot mills built by them, is a fully-enclosed, oil-film, sleeve-type bearing, in which the inner and outer races, instead of being separated by balls or rollers, are separated by an unbroken film of oil. It is this film of oil, of tremendous load-carrying capacity, that differentiates the Morgoil from other types of roll-neck bearings, and gives it its unique performance characteristics.

Full utilization of the principle of oil-film lubrication would be impossible, however, without suitable bearing design that features intelligent use of available metals, both on the bearing surfaces and in other constituents of the whole bearing. Materials for chock, sleeve, bushing, thrust rings, water seals, lock nuts, etc., have all been carefully selected and treated to perform certain definite functions. Fundamentally, and particularly in performance, the Morgoil bearing is comparable to the roller bearing, for the power savings achieved with either of these in comparison with the old plain bearing are of the same degree; also, both the roller bearing and the Morgoil bearing (and only these) have been successfully applied to the back-up rolls of 4-high mills. In direct comparison with the roller bearing, the Morgoil bearing is much more compact for equivalent load-carrying capacity, and its use thus permits using rolls having very large diameter necks. The operating life of the Morgoil bearing has not been determined, as the early installations—made over 7 years ago—are still operating most satisfactorily; its maintenance cost is evidently lower than that of any other type of bearing. Roll-changing is also a simpler, quicker job with Morgoil bearings on the necks than with roller bearings. Some performance data and experiences will be cited later.

Metallurgical Design

The metals used in the Morgoil bearing, as well as the all-important oil-film lubrication, are of fundamental importance in obtaining successful operation. Particularly interesting are the materials, and the metallurgical treatment given them, that make up the sleeve, the bushing and its lining, and the thrust rings.

A diagram of the construction of the bearing is shown in Fig. 2. All parts of the bearing are fully enclosed in a heavy chock of cast 0.50-0.60 per cent C steel. The inner race of each bearing is a sleeve, made of forged nickel-molybdenum steel, which in operation is keyed to the roll-neck and rotates with the latter. This important feature means that the sleeve, rather than the roll-neck, serves as the bearing journal. Surrounding the sleeve is a steel bushing, lined with cadmium-nickel bearing metal (American Smelting and Refining Co.'s "Asarcoloy") centrifugally cast in place. The surface of the cadmium-nickel alloy is accurately machined with a diamond tool, and the highly polished sleeve (see Fig. 1) rotating inside this bushing is separated from it by a constantly replaced oil film of very high load-carrying capacity.

The flange at the outboard end of the sleeve rotates between two thrust rings, made of cast steel and faced with the same cadmium-nickel alloy used for lining the main bushing. Thus, there is provided a double acting thrust bearing designed to withstand all axial thrust loads encountered. Thrust ring clearance is regulated by a very simple adjusting and locking mechanism; complete flood lubrication prevents wear. In operation, the bearings on the operating side of the mill are clamped to the housing and carry the thrust load in either direction, whereas those on the drive side are not axially restrained in the housings. The thrust bearings on the drive side thus serve the sole purpose of positioning the chocks with respect to the roll necks.

Oil is retained in the bearing by seals of conventional type at both inboard and outboard ends. The inboard seal is a double seal; the element toward the roll barrel serves to prevent the entrance of foreign matter to the bearing. As an additional precaution, a seal ring of lead bronze bearing alloy is held against the end of the roll barrel under light spring pressure.

The Sleeve

Nickel-molybdenum steel (S. A. E. 4620) was selected for the sleeve because of the need for a material of high strength, capable of taking a hard durable case, and susceptible to an absolute minimum of distortion during heat treating. The sleeves, depending on the sizes of bearings ordered, have been made in a wide range of sizes and load capacities, from $6\frac{7}{16}$ in. diam. and $4\frac{3}{4}$ in. long (90,000 lbs. capacity) to 44 in. diam. and $44\frac{1}{2}$ in. long (5,250,000

Fig. 4. Diamond-tool Boring of the Inside of the Bushing to Give the Lining its Super-fine Finish. (Courtesy: Worcester Sunday Telegram)

lbs. capacity). The largest sleeves weigh over 2½ tons, when finished.

The forgings are received in the rough-machined condition, *i.e.*, with ⅛ to $\frac{3}{16}$ in. for finish, depending on the size. Before machining, they are annealed by heating at 1800 to 1850 deg. F., and furnace-cooling to 200 deg. F. After machining, they are pack-carburized, hardened and tempered to 550 Brinell hardness. Finally, they are ground to the mirror finish illustrated in Fig. 1. Recent tests made with a Profilometer show that the journal surfaces are ground to within 0.000004-0.000007 in. of perfection. The use of a minimum-distortion carburizing steel is necessary to avoid having to leave an excessive amount of "finish" for grinding.

The sleeve, it will be noted, is of tapered bore and cylindrical outer surface. Tapered neck bearings are used in most installations because the tapered construction gives greater strength and stiffness to the roll neck particularly at the fillet, and because the mounting and removal of the bearing are much simplified. In changing bearings from one roll to another, it is not necessary to dismantle the Morgoil bearing itself; the bearing is removed from the neck as a unit by unscrewing the lock-nut, and removing the entire bearing assembly intact, including the sleeve. When turning or grinding rolls, the Morgoil bearings need not be removed at all; a roll may be mounted in the lathe or grinder with the bearings serving as journals for the roll during the machining or grinding operation.

The Bushing

The bushing of the Morgoil bearing is low-carbon steel in the form of curved and welded plate, on the bore of which is centrifugally cast a layer of cadmium-nickel bearing alloy. After welding, the steel bushing is annealed, then machined, and finally very carefully cleaned before being placed in a special centrifugal casting machine for deposition of the Asarcoloy bearing surface. The centrifugal casting operation is illustrated in Fig. 3.

The thickness of the cast-on layer of cadmium-nickel alloy is very important, and varies with the size of the bearing; also vital to the successful performance of this layer are its finish and adherence. A superfine, extremely accurate finish is produced by boring with a diamond tool at a very high speed and small feed; this operation is illustrated in Fig. 4. The centrifugal casting operation and the inherent bondability of the bearing alloy to steel give a bond strength equal to the ultimate strength of the cadmium-nickel alloy itself. In the manufacture of the bearing the bond is checked for each bearing immediately after the centrifugal casting operation, and before the diamond-tool boring, and if the bond test shows any weakness, the bushing is rejected.

With almost perfect surfaces of bushing-lining and sleeve, the oil film between them can be extremely thin and still prevent metal-to-metal contact. It is the oil-film that gives the Morgoil bearing its most useful characteristics: a coefficient of friction between 0.0012 and 0.0035—roller bearings run between 0.0020 and 0.0030—and freedom from wear and compressive fatigue of the bearing races. The oil film efficiently spreads the load and prevents the type of local stress concentration that occurs in ball or roller bearings, where the rollers are repeatedly pressed against the race, resulting ultimately in spalling or cratering of the latter—the compressive fatigue previously mentioned.

The fool-proof, minimum-friction operation of the Morgoil bearing is more the result of the efficiency of the oil-film than of any other single factor. The nature of the bearing alloy, however, is of contributory importance. According to Morgan,[12] no matter how close to perfect the machining is, some few irregularities occur—a new bearing contains tiny hills and valleys and the hills cut through the oil film. Bronze or copper-lead alloy bushings have a high coefficient of thermal expansion, so that if the oil film is broken, the hill expands and the area of poor lubrication is enlarged. In the case of a soft metal (like cadmium-nickel alloy), the hills are pushed off into the valleys and the oil film is re-established before the low-expansion alloy has a chance to spread its protruding areas.

Other considerations that led to the selection of the cadmium-nickel alloy for lining the bushing were its satisfactory compressive strength and its superior bondability to steel. Oil-corrosion of the cadmium-nickel bearing alloy, so often a limiting factor in its application in certain types of engines (usually where high crank case temperatures are encountered), is avoided by the use of a straight mineral oil free from acid-forming constituents and by control of oil temperatures.

Lubrication of the Morgoil bearing has been thoroughly discussed in other publications,[13, 14] which gave full details of the circulating system and characteristics of the lubricant. In Morgoil bearing lubrication, the oil is circulated under "flood" conditions (*i.e.* every part of the bearing is fed an oversupply of oil) from a central system. Pressures range from 10 to 15 lbs. per sq. in., and the oil is continuously filtered, with automatic control to prevent failure of the supply.

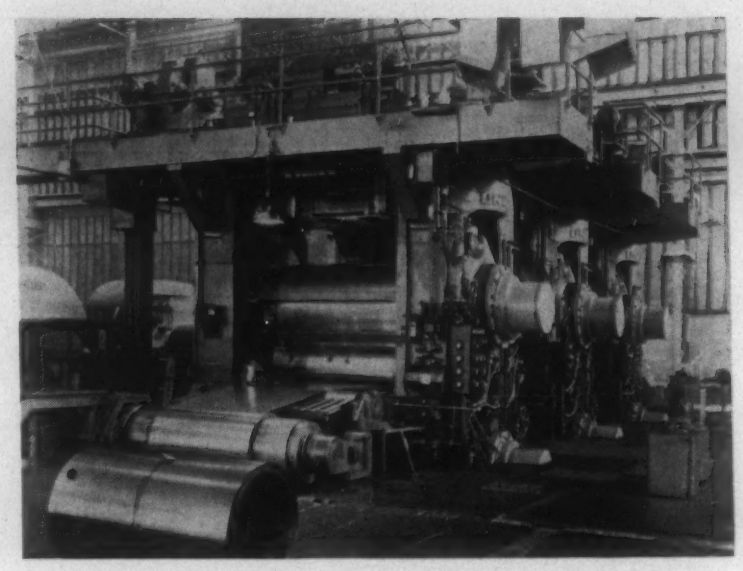
Operation and Performance

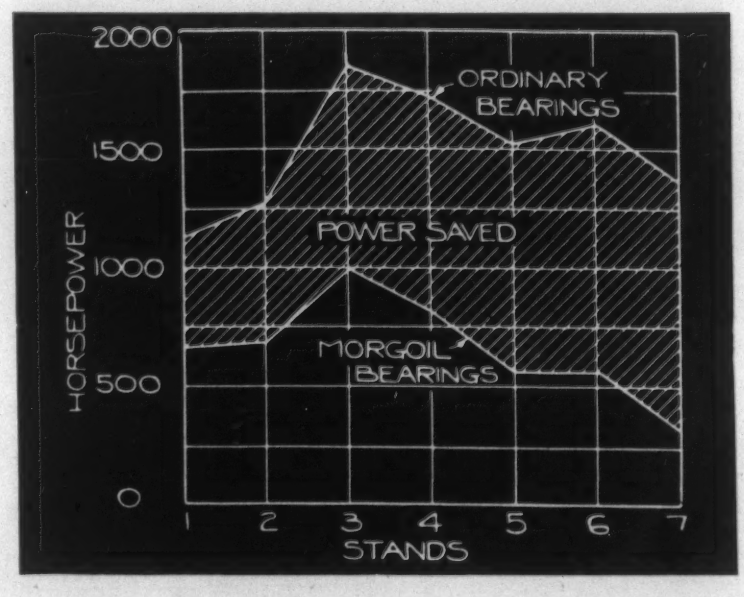
The record contains much evidence that intelligent design and the careful selection of materials have made the Morgoil bearing a highly efficient and generally superior product. In power savings alone, the old plain metal bearing cannot be compared to it, as the data in the Table (supplied by the Morgan Construction Co.) for a 12-in. continuous hot strip mill

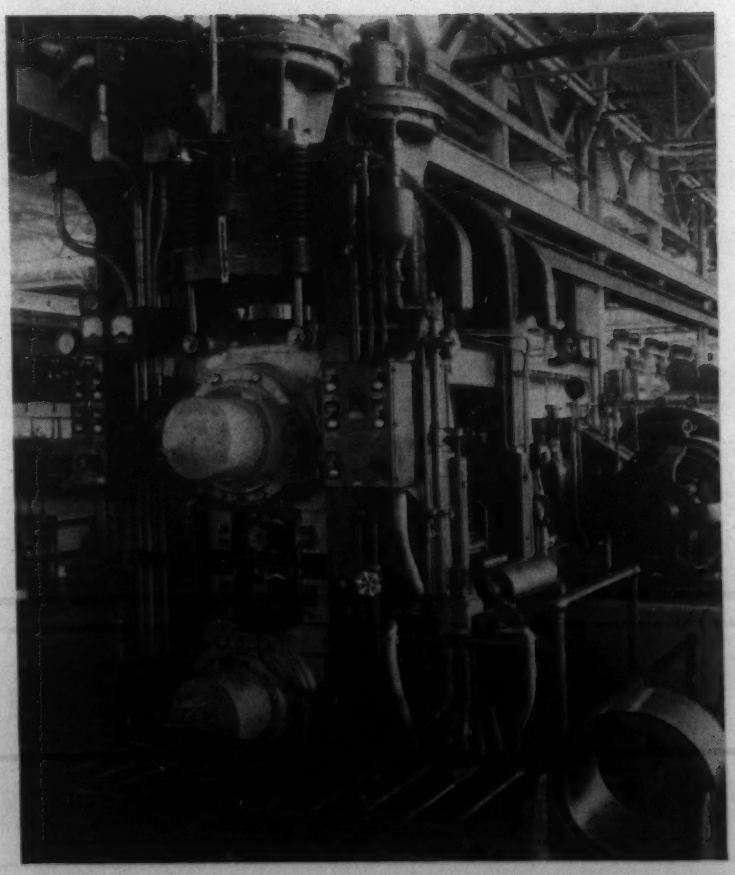
Fig. 5. (Top) Modern 3-stand Tandem 4-high Cold Mill Equipped with Morgoil Bearings.

Fig. 6. (Center) Comparison of Power Consumption on 21-in. Sheet Bar Mill, Rolling 12 in. x 0.309 in. Tin Bar, with Morgoil Bearings.

Fig. 7. (Bottom) Morgoil-equipped 4-high Cold Mill at Bridgeport Brass Co.







show. Fig. 6 gives a graphic demonstration of the power savings observed on another mill in which old-fashioned bearings were replaced with Morgoils.

More interesting, however, because of the completely disinterested source, is the published comment of one user of Morgoil bearings, G. S. Warren,[15] who says they have "made it possible to double the capacity of our old 2-high hot and cold strip and bar mills, without increasing the capacity of the drives." The mills in question, at the plant of the Sharon Steel Corp., had previously been equipped with old plain-metal bearings. Warren goes on to say that his company, in 1932, was the first to use the Morgoil bearings; the original Morgoils are still operating, and have given no serious trouble. Bushing renewals have been "very few." Sharon has also succeeded in doubling the capacity of their 2-high cold strip mills, rolling stainless steel, by replacing old plain metal bearings with Morgoils.

Clearly superior to the barnyard bearing, the Morgoil is evidently on a par with the roller bearing. Both types are now being employed in mills of the same general nature, with the advantage going to Morgoils where it is necessary to have as large a diameter of roll neck and high load-carrying capacity as possible. Hitchcock,[16] in discussing several Morgoil installations, cites the case of a 2-high reversing hot strip mill of the Steckel type, the roller bearings of which were replaced with Morgoils. The latter provided no power savings, but allowed the use of a larger roll neck, and eliminated neck breakage, a factor that previously had prevented the mill in question from operating profitably.

With the trend toward faster and faster operation at heavier and heavier loads, the higher load-carrying capacity of bearings of the Morgoil type is being increasingly utilized. In a recently published survey of rolling mill progress in the last 2 years, Badlam[17] states: "The most conspicuous feature in the design of the more recent broad strip mills, both hot and cold, has been the almost exclusive use of bearings of the oil sleeve type, instead of roller bearings, on the backing rolls. The use of the roller type bearings on the working rolls, however, is still universal."

Morgoil bearings are also successfully used for the roll necks of non-ferrous mills, as is illustrated in Fig. 7. One of the most interesting non-ferrous ap-

(*Continued on page 196*)

Improved Microtome for Soft Metals

If we remember correctly, when the microtome method for preparing soft metals for metallographic examination was first put forth the only suitable microtome cost about $1,000, and it was a major catastrophe if the knife became chipped and had to be reconditioned. The outfit was very definitely tailormade.

It is a delightful application of common sense to utilize low cost equipment designed for other use in place of the original special and expensive equipment. Presenting the details by which this application is made possible, as Schumacher and Bouton do in this article, will enable many a laboratory to save money and will encourage the use of the microtome where first cost and upkeep have hitherto made it inapplicable.—The Editors.

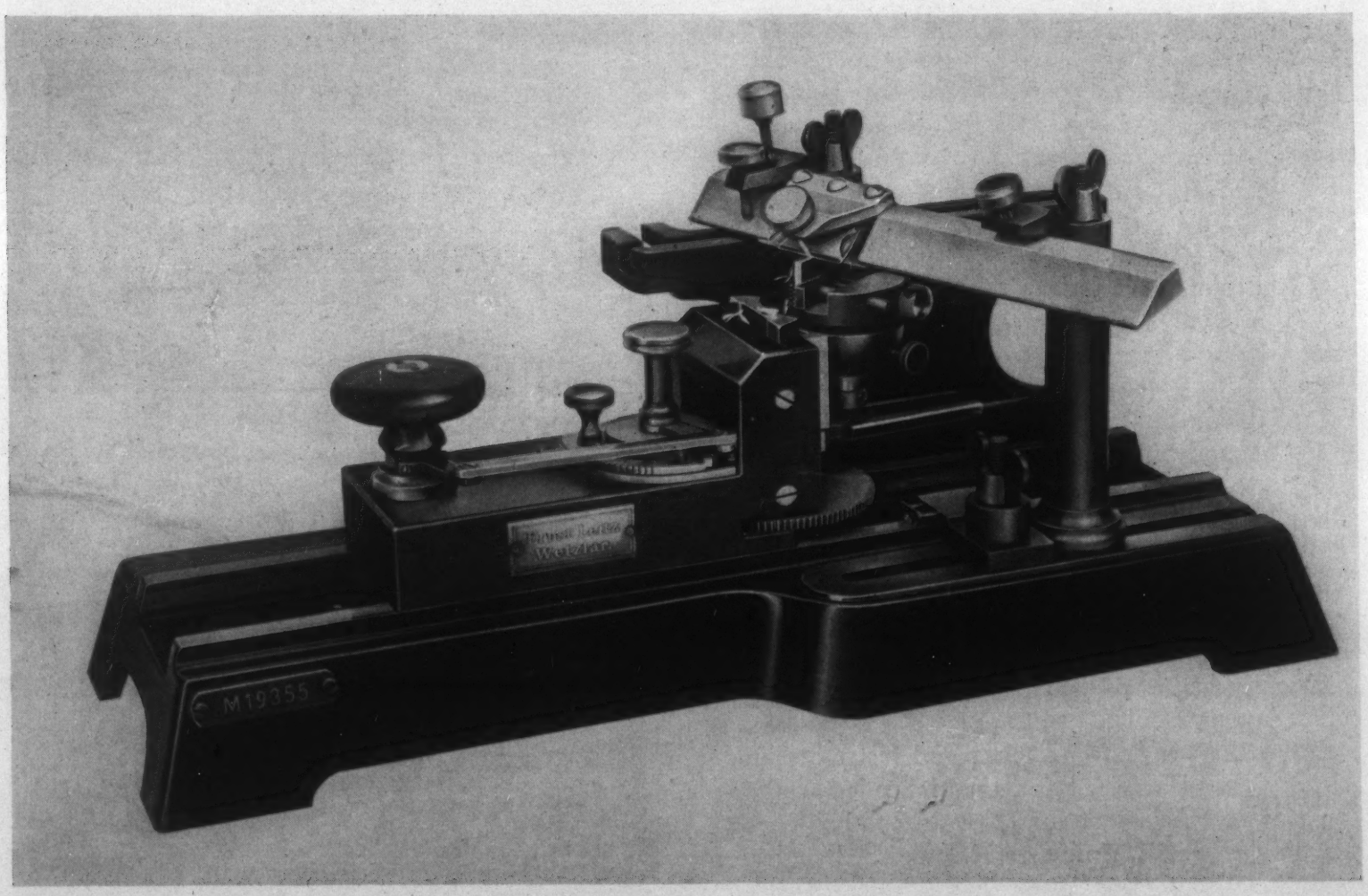


Fig. 1. Photograph Showing "Rolls" Blade in Adapter being Used for Sectioning a Lead Cable Sheath Specimen in a Microtome.

by EARLE E. SCHUMACHER and G. M. BOUTON

Bell Telephone Laboratories, Inc., New York

IN THE PAST, the use of the microtome method for preparing soft metals for microscopic examination has been handicapped by the skill and time required to produce a satisfactory edge on the cutting blade. At the Bell Telephone Laboratories this objection has been overcome by adapting the commercially available "Rolls" razor and its associated semi-automatic sharpening equipment to microtome use. This has resulted in important savings in time and improvements in the results obtained.

The benefits derived from the substitution of the razor blade for the conventional microtome knife accrue in part from the mechanizing of the sharpening operation and in part from the small size of the blade. The sharpening device supplied with the razor brings each side alternately in contact with the sharpening surfaces, always maintaining uniform pressure and constant contact angles. This, to a large measure, insures the production of a sharp edge even by a person inexperienced in the operation.

Also, since the unit is compact and always ready for use it is only a few minutes work to insert the blade and recondition the edge. The smallness of the blade, which is only 1¼ in. long, simplifies the manipulation difficulties considerably during the sharpening process. Moreover, should the edge be deeply nicked in course of use, only this short length of blade need be sharpened whereas previously it was necessary, in the interest of keeping the edge straight, to grind and strop a length of several inches. This required considerable expenditure of time and effort.

There have been several proposals in the past to use the ordinary wafer type safety razor blade in microtomes. While this type of blade may have been used satisfactorily for some biological applications, the present writers have not found it suitable for metal sectioning. The edge of this type of blade is too thin to cut without chattering or breaking and, as commercially supplied, does not have the character required to produce a surface on the metal specimen suitable for microscopic examination. Besides, the mechanical sharpeners available for sharpening wafer type blades do not produce the desired type of edge and do not lend themselves to ready modification.

The microtome used by the authors for sectioning cable sheath alloys is shown in Fig. 1. While originally intended for biological use it has functioned very satisfactorily for metal sectioning. It is sufficiently sturdy for use on lead cable sheath alloys in thicknesses up to 0.250 in. The clamp for holding the "Rolls" blade is shown in more detail in Fig. 2. It is not believed that the design is critical except that the top and bottom surfaces of the clamp that come in contact with the blade should fit the curvature of the blade rather closely and, to insure rigidity, should extend as near to the edge of the blade as practicable. More specific details and dimensions are not presented here because of the simplicity of the design and because the dimensions will vary with different types of microtomes.

For metal sectioning it has been found desirable to impart greater stiffness to the cutting edge by grinding the "Rolls" blade somewhat narrower. This also produces a slightly blunter cutting angle. This operation need, of course, only be done once but, since it is very important that it be done correctly, details are given here. The shortening of the blade can be accomplished most conveniently by holding it perpendicularly against the flat side of a power grinding wheel, the usual care being taken to avoid overheating. It is well to check the progress of the grinding with a micrometer, the operation being completed when the distance from the back of the blade to the new edge is 0.800 in. throughout its length. The edge should then be smoothed and straightened by holding the blade perpendicularly against the flat side of a "Hard Arkansas" oil stone and rubbing until examination with a magnifier shows that the entire edge has been in contact with the stone, and all of the marks from the grinding wheel have been removed. The sides of the blade may then be rough ground on a power grinder to form a blunt cutting edge, care being taken not to remove all of the flat surface at the edge produced by the previous operation.

The next stage of sharpening is best accomplished by rubbing on metallographers' French emery paper Nos. 1 and 00. The paper is elevated above the surface of a sheet of plate glass by a sheet of cardboard or metal about 0.02 in. thick. The knife bevel of the blade is placed on the paper and the back or thick edge of the blade is allowed to overhang and slide on the glass. This fixes the rough grinding angle of the bevel. The blade is rubbed back and forth in a direction parallel to the edge of the No. 1 paper, a few strokes alternately on each side of the blade, until the bluntness of the edge can no longer be seen with a magnifier. During this operation the edge of the blade should be held at an angle of about 15 deg. to the edge of the paper.

At this stage the edge should again be smoothed and slightly blunted by rubbing lightly with a small "Hard Arkansas" oil stone held in the hand. The dihedral angle between the surfaces of the stone and blade should be about 60 deg. While this process requires some judgment on the part of the operator, a little experience will show the correct amount of dressing required. After smoothing, the blade is further sharpened on No. 00 emery paper until the coarse scratches left by the No. 1 paper have disappeared. The edge in this case is also held at 15 deg. to the edge of the paper but in the opposite direction so that the fine scratches of the No. 00 paper intersect those left by the coarse paper at about 30 deg. The edge is again smoothed with the Arkan-

Fig 3. Standard "Rolls" Sharpening Device with Blade in Place for Stropping. For honing, the cover containing the stone is put in place and the strop removed.

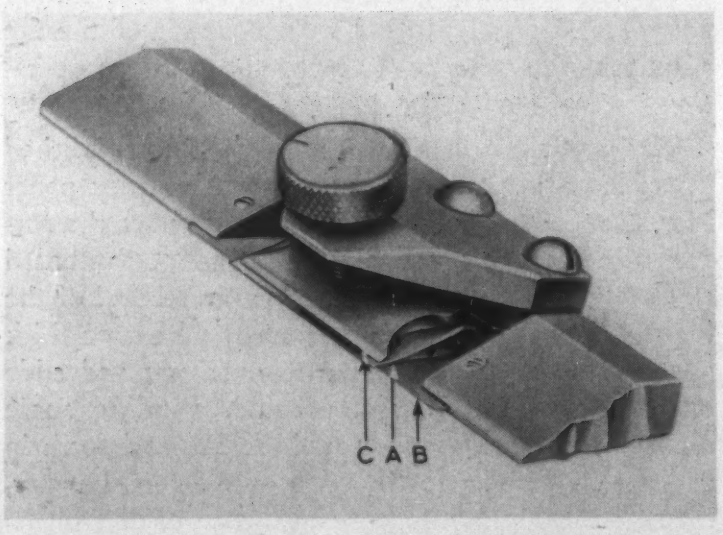


Fig. 2. Close Up View of Clamp with "Rolls" Blade (a) in Place. The lower plate (b) and the upper plate (c) are curved to fit the hollow ground sides of the blade.

sas stone. This repeated dressing is required to prevent a "feather edge," which is too fragile, and to remove the saw tooth effect commonly associated with razors because it would leave ridges on the specimen.

The final stages of sharpening are conducted on the "Rolls" sharpener as shown in Fig. 3. When the blade is used only for cutting soft materials such as lead-rich alloys this will be the only part of the sharpening operation required to keep the once properly prepared blade in perfect condition. The blade is honed on the stone supplied by the manufacturer until inspection shows that the full length of the edge has been honed. This will not require much time since the honing angle is less acute than that produced by the emery paper operation and thus only the region near the edge receives grinding. The stone is then removed from the sharpener and the strop put in place and sprinkled with No. 400 Alundum polishing powder. About two minutes stropping of the blade produces an edge condition that is satisfactory for most purposes and which is, in fact, considerably superior to the edge usually produced on the large conventional microtome blades. Still better results can be obtained, if a hard "Arkansas" hone is obtained, fitted to an additional hone holder, and used between the two steps described above, and if an additional stropping is given on the standard rouge dressed strop after the operation with the No. 400 Alundum.

A few simple tests will establish whether or not the sharpening has been successfully accomplished. The razor blade sharpened as described should make a cut one micron deep without curling, splitting or seriously distorting the shaving. The knife should not drag on the specimen on the back stroke nor should it leave a fringe of fine lead particles clinging to the edge of the specimen. The edge condition of the blade may be further verified by observations on a high purity lead test specimen. After having a series of slices two microns in thickness removed, such a specimen should not show surface recrystallization when etched six seconds in a 3:1 glacial acetic acid: superoxol mixture followed by a few seconds immersion in a 3:4:16 mixture of acetic acid: nitric acid: and water. While, after etching, knife lines may be visible at 18X magnification they should not interfere with photography at 100X or higher.

Tensile Testing in the Manufacture of Wire

by G. C. STAUFFER

Assistant Manager, Technical Department,
Driver-Harris Co., Harrison, N. J.

IN THE EARLIER DAYS of wire manufacture (in fact, as recently as 8 or 10 years ago,) the principal object in tensile testing of wire was to determine its strength. Most testing routines were for the purpose of checking production to make certain that the breaking strength was up to the standard required by the user, or arbitrarily set by the maker.

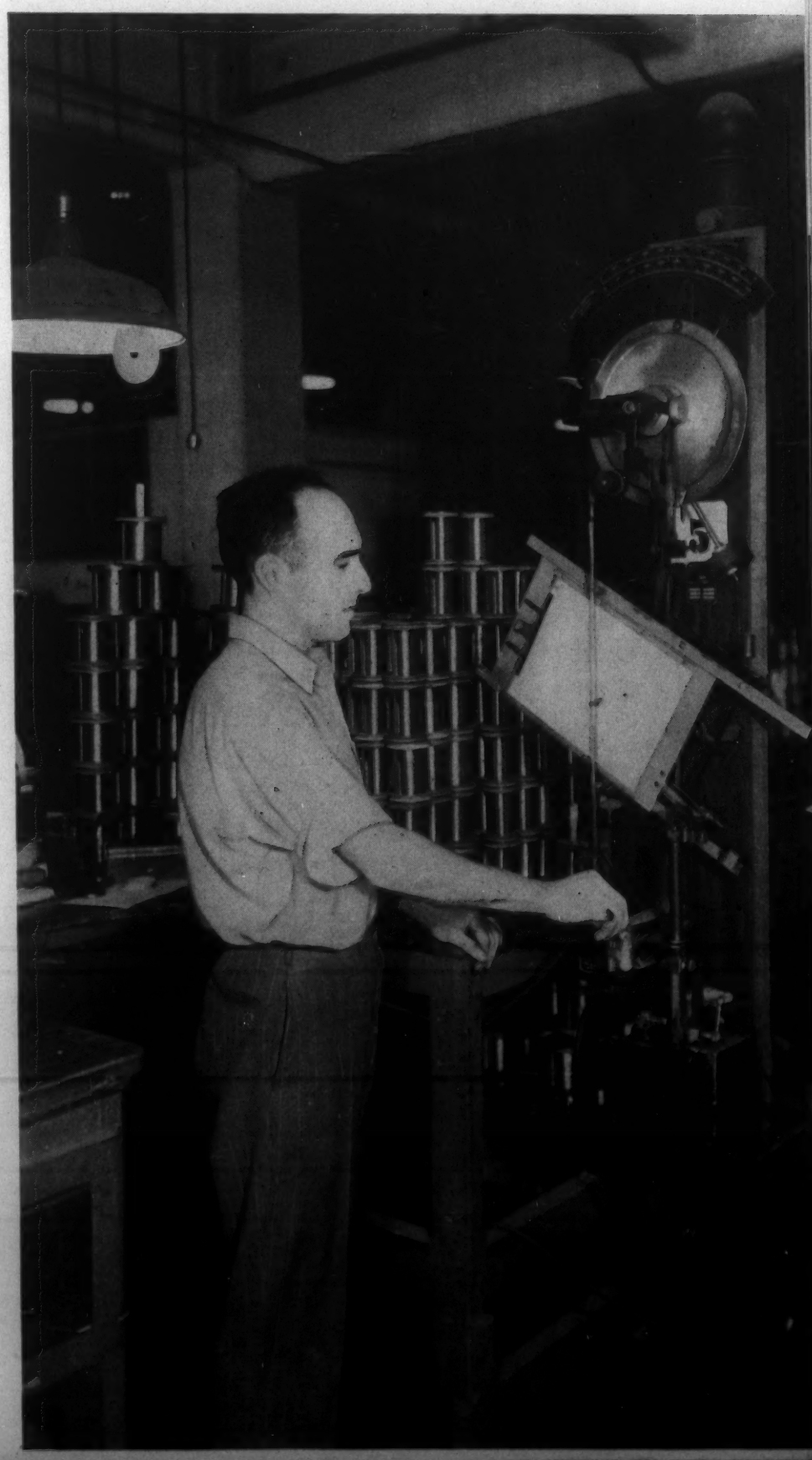
For a simple strength test, the dead-weight bucket method served reasonably well. We used it extensively at Driver-Harris for years.

But today the multiplicity of uses to which wires are put, makes it imperative that wire be produced with accurate control of other tensile properties as well as strength. The call is for wires with definite characteristics of elongation and elasticity. This makes it necessary to use tensile testing apparatus which gives a complete picture of all the tensile properties of the wire.

In line with this development, we have in recent years installed wire testing apparatus which gives a "picturized" result, showing graphically on a chart the characteristics of the wire so clearly that the tensile properties of the wire are revealed without need for calculation.

These machines, which are made by the Henry L. Scott Co., Providence, R. I., are of the vertical inclination balance type. The lower end of a specimen of predetermined length is pulled downward at uniform speed by a motor driven train of gears. The upper end is attached to a bar transmitting the pull to a dead weight pendulum designed to give constant speed of pull. The autographic recorder is so arranged as to co-ordinate in one line the two movements, one being the net separation of the jaws, the other indicating the load or stress. This automatically gives us a picture of the load-stretch conditions throughout the testing cycle. We see on the chart the elastic limit or yield point, the total tensile, total elongation, and ultimate separation.

Making a Tensile Property Test of Fine (0.004-in.) Radio Tube Grid Wire on a Scott Vertical Inclination Balance Tester.



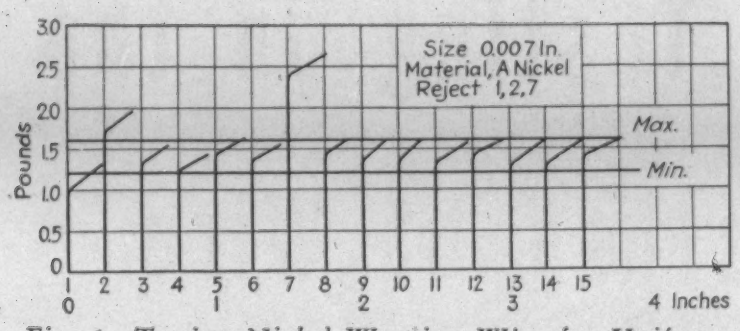


Fig. 1. Testing Nickel Weaving Wire for Uniformity of Yield Point: Limits, 1.2 lbs. min., 1.6 lbs. max.

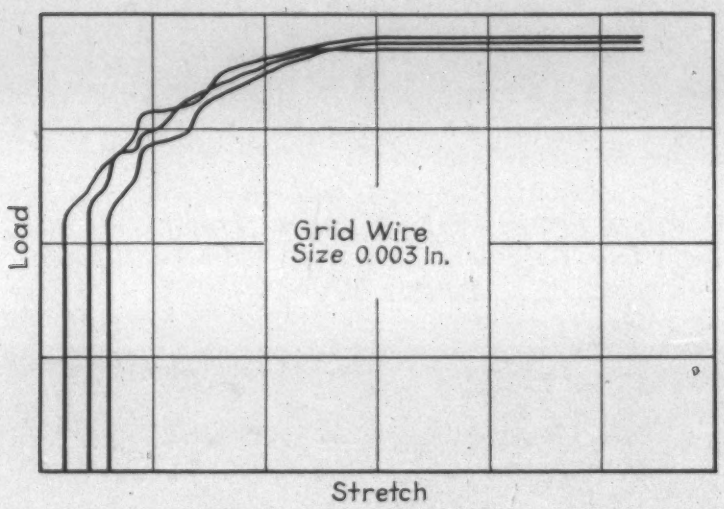


Fig. 2. Test on Radio Tube Grid Wires for Uniform Rate of Elongation. Considerable fluctuation from constant curve indicates superior ability of wire to retain grid shape in operation.

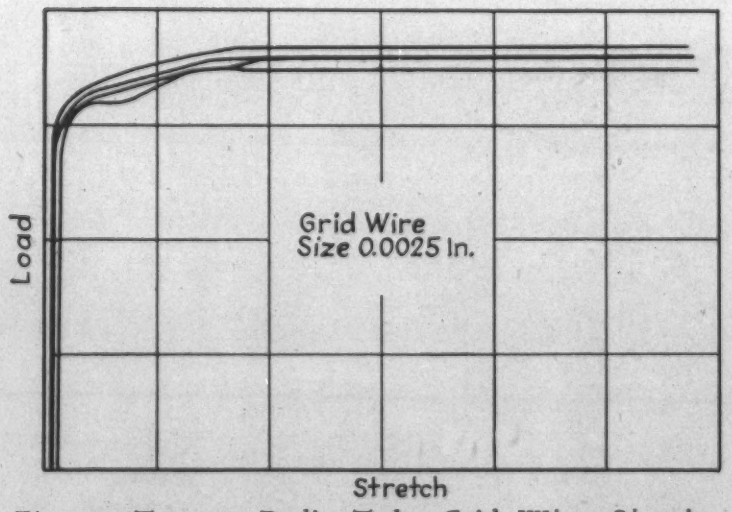


Fig. 3. Test on Radio Tube Grid Wires Showing Desirable Uniformity of Curve, as Contrasted with Fig. 2.

Factor of Elasticity

Let us examine first the factor of elasticity. Uniformity in this respect is extremely important in wire for weaving. The point here is that all the wires, particularly the warp wires, must start to stretch at the same tension. Otherwise, although all the wires were pulled taut, some would give way much more easily to lateral pressures than others and the result would be an uneven fabric, a serious defect in fine metal screens, for example.

A simple elongation test would be of little value in this instance, as the requirement is that the wires yield at a uniform tension.

In the old days, foremen in the wire weaving plants were accustomed to select wire by manual tests, stretching it between their fists, and getting the feel of whether it was too stiff, too yielding, or just about right.

Today these plants specify wire with a yield point falling within definite limits. Fig. 1 is an example of routine testing on nickel weaving wire of 0.007 in. diameter. Here the customer's specification is a yield point of 1.2 lbs. min. to 1.6 lbs. max. Every spool on such orders is individually tested. In this case, spools Nos. 1, 2 and 7 were rejected, spool No. 1 having too low a yield point, and No. 2 and No. 7 too high. Note that no attempt is made to determine the strength of the wire. The machine is stopped the instant the yield point is clearly indicated. Actually, the breaking strength of this particular wire is around 3 lbs., which is probably twice the tension ever put on the wire either in weaving or in service.

Wires for Radio Tubes

The situation with regard to radio tube wires is most interesting. These are delicate wires, 0.003 in. and up for grid wires, and as fine as 0.0008 in. for filament. The grid wires especially present a problem, because they are required to be formed into definite shapes which must remain, within very narrow limits, at a fixed distance from the plates or filaments inside the hollow grid formed by the wires.

Major emphasis in specifying such wires has been laid by tube manufacturers on high elongation, as evidence that the wire had been properly annealed and would take sufficient "set" during winding on the grid frames to assure retention of the grid size. Some grids are round, others oval, others round cornered rectangles, and so forth in great variety.

Some of our tube wire customers, who formerly tested their grid wire on simple elongation machines operated by hand, are now equipped with Scott testing machines, which have the ability to test single strands of the finest wires. As a result of this fact, they are enabled to give us very helpful information in specifying the types of wire they require. As one

of these firms recently expressed it: "It gives us a picture of the wire." In their specifications to us, they occasionally rely on such "pictures" in lieu of specific formulae.

Fig. 2, for example, is an instance. This user has had experience indicating that wires which fluctuate from a steady curve beyond the yield point have a tendency to be adversely affected by the operating heat of the tubes much more than wires with an even curve. Fig. 2 shows a picturized test of a fluctuating wire, while Fig. 3 shows four specimens, one of which was rejected. It is apparent that ordinary elongation testing could not reveal such variations; and without this method of picturized testing, it would be difficult for the user to describe to us what he prefers. As it is, from our examination of their charts, we can formulate and treat our wires for them to match the type of curve they have found indicative of properties which give them best service in operation.

This is but one small facet of the subject of radio tube wires, which is one of the most fascinating problems facing the wire manufacturer today.

An interesting instance recently occurred in connection with formulating special wires to customer specifications. We made up for a customer four large spools of 0.005 in. wire of a high nickel alloy containing several other metals for the customer to test. It was all made in one batch, but when the customer came to use it, he reported that two of the spools were just what he wanted, but that the other two were not the same thing at all. As we had made picturized tests of samples from each spool, we knew they were all very closely alike, and we offered the charts as proof. Eventually it was discovered that in using the third and fourth spools the manufacturer had somehow produced a twist in unspooling, and this was the cause of the trouble. The instance is cited merely as an example of how the testing records saved much useless back-tracking.

Zinc Wire

As every metallurgist knows, zinc can be a troublesome metal to work with, due to the fact that minute traces of impurities cause major variations in physical properties. We supply considerable quantities of wire for weaving in combination with non-metallic yarns for automobile brake linings. Much of this wire is zinc. In its pure state, zinc is comparatively soft, and for this reason greater or less amounts of impurities are either introduced or permitted to remain in it in order to give it hardness. Suffice it to say that a variation of as little as 0.06 of 1 per cent in purity can result in 100 per cent difference in physical characteristics.

In purchasing zinc, therefore, we are able to put our testing machines to valuable use. Fig. 4 is a condensed example of a large number of tests made

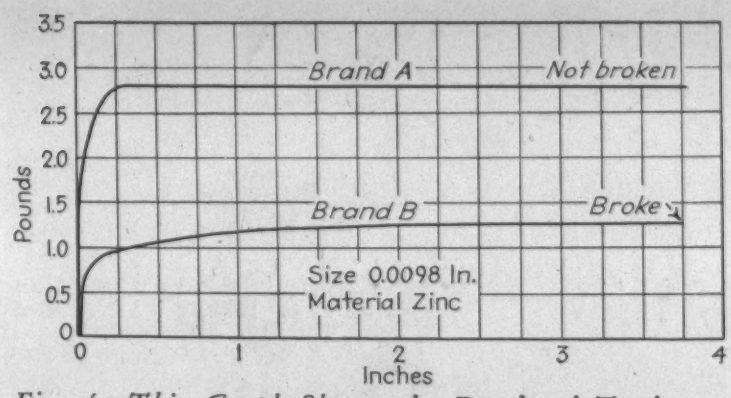


Fig. 4. This Graph Shows the Result of Testing a Considerable Number of Zinc Wires, Omitting All but the two Extremes. An interesting example of the great variation in zinc caused by minute amounts of impurities.

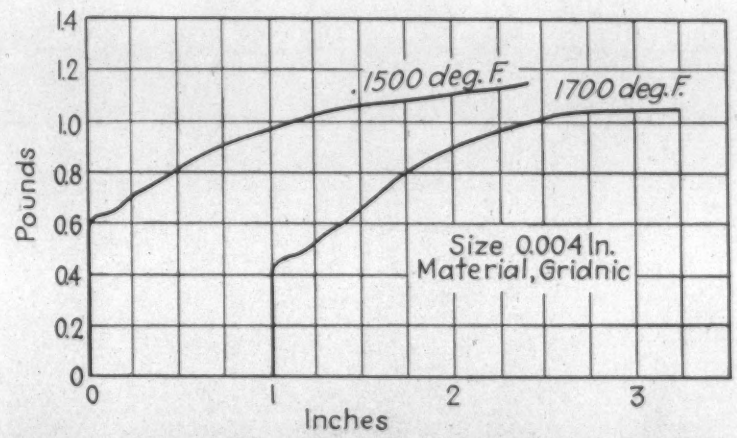


Fig. 5. This Chart Shows the Variation in Physical Properties of the Same Wire (0.004 in. Gridnic Wire) Annealed at Constant Speed but with Varying Temperatures.

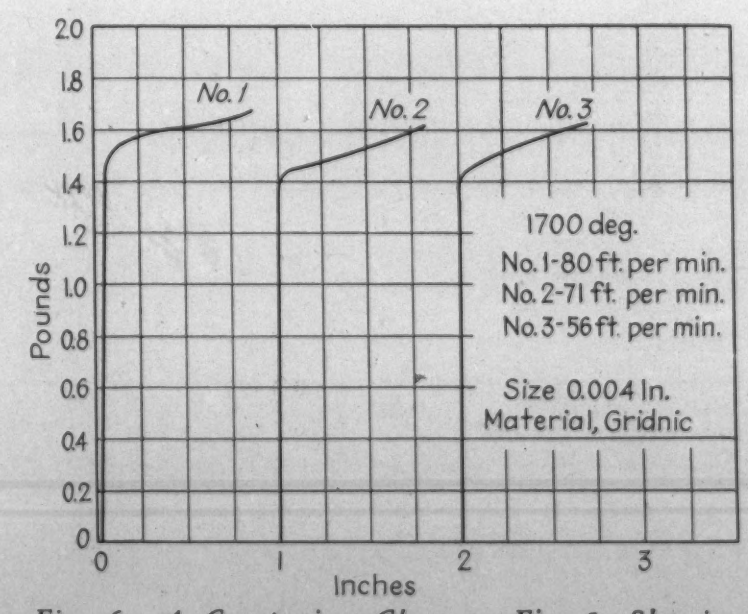


Fig. 6. A Companion Chart to Fig. 5, Showing Variations in Physical Properties Produced by Varying Speed through Annealing Furnace, Temperature Constant.

Testing Nickel Weaving Wire on a Scott Machine to Determine Uniformity of Yield Strength and Other Tensile Properties.

to select a satisfactory brand of zinc for brake lining wire. To the user of this wire tensile strength is important, but it is also essential that the elongation be high. A large number of samples were tested in a very short time and we were quickly enabled to decide what brand we should use for this customer. A considerable number of specimens were tested, ranging in performance between the two extremes presented on the chart, and all of the specimens could properly be called "zinc." Note that Brand A was more than twice as strong as Brand B, 115 per cent to be exact, and that at the same time it possessed higher elongation.

Testing in Research

In addition to routine production testing, and to process control through testing, we also find this picturized testing valuable in research work.

Figs. 5 and 6 are taken from series of tests made during experimental work on 0.004 in. wire intended for radio tube grids. This wire is annealed continuously through tubes in a long furnace and is spooled as it comes out of the furnace. The object of the investigation was to observe the effects on the physical properties of the wire, produced by varying the temperature and the speed of progress through the furnace.

Fig. 5 shows the effect of varying the temperature, the time remaining constant, while Fig. 6 illustrates the effect produced by varying the time of annealing, the temperature remaining constant.

From the few examples cited in this article, it is readily apparent that the importance of testing to the wire manufacturer has increased in proportion as the effectiveness of testing apparatus has improved. Even a brief examination of the charts illustrated, shows that neither a simple elongation test nor a simple tensile test could give the detailed picture of the wire as revealed by the coordinate line. Because of this "picturizing," we have been enabled to study and control characteristics of behavior much more closely in the widely varied line of wires we produce.

Metals and Alloys at the New York World's Fair-II

Supplementing the presentation, in our May issue, of some of the striking uses of metals and alloys at the New York World's Fair, 1939, there will be found on this and the following pages a few more illustrations which were not obtainable for the first collection.

We called attention in the May issue to the unusual use of welded sheet and strip in the formation of statues, particularly the statue of "Mercury" on the Ford Pavilion. We present in this collection a photograph of this statue, made of stainless steel. In the same Ford Pavilion is an imposing "activated" mural, largely of metal, also reproduced here.

In the line of murals, we called attention last month to the metal mural in the building of the United States Steel Subsidiaries. In this month's presentation we are able to reproduce a photograph of this very beautiful and unusual production—"Steel in Steel."

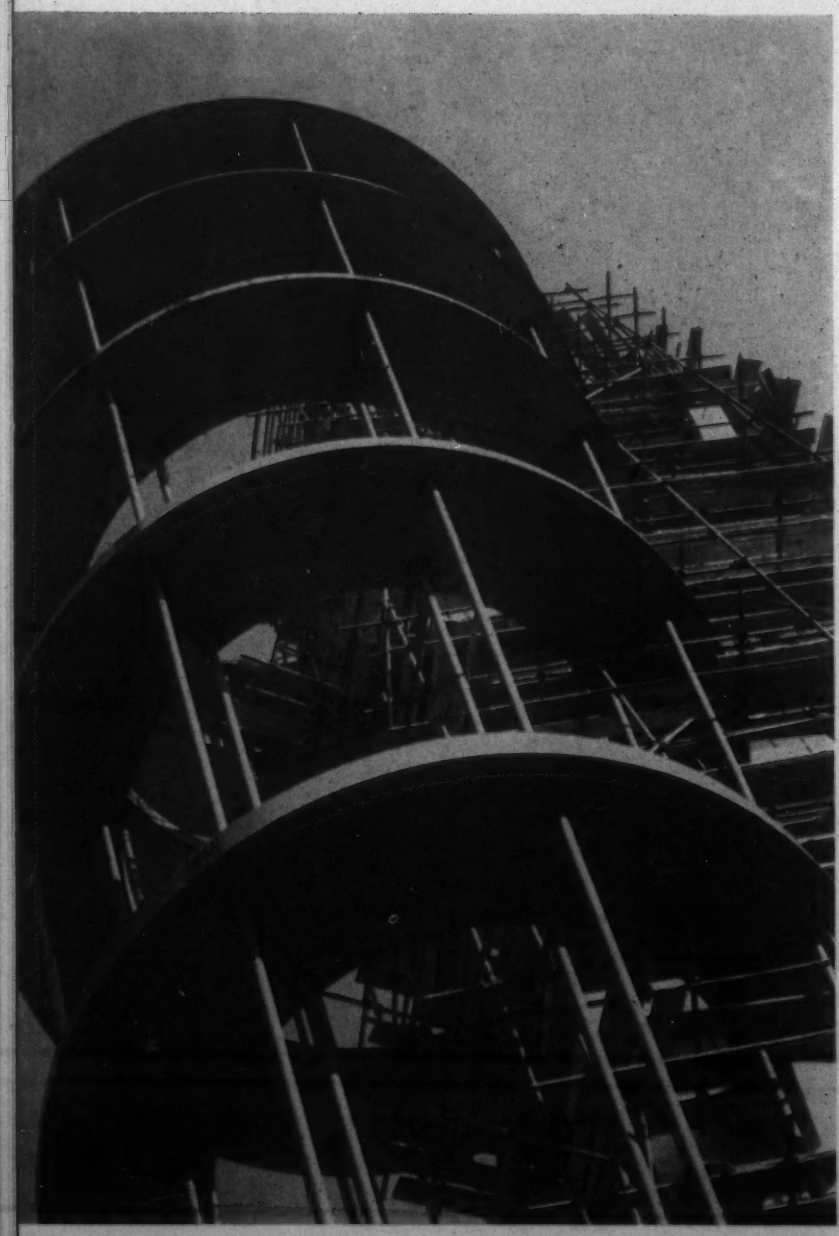
One of the most effective buildings, so far as metals are concerned, is that of the General Electric Co. A photograph of this is reproduced. Near this building is the Westinghouse Pavilion with its Singing Tower, an example of unusual steel construction.

It is of interest to note that lead and aluminum figure in various displays. In the Court of Peace is an heroic statue of Norway's great king, Olav Trygrason (1000 A.D.). It is 12 ft. high, weighs 3 tons and is coated with sheet lead. In the impressive 7½-acre display of General Motors, the facade of one of the buildings—the Auditorium—is of thin aluminum sheets on plywood.

These and the citations a month ago emphasize a distinct trend in the application of metals and alloys as statues, murals and so on in the World of Tomorrow.—E.F.C.

A Night View of the General Electric Building. The entire building is sheathed on the outside with copper. Up in the night sky, 129 ft. above the pool, a huge sphere seems to shrink and swell in a ring of light, then a jagged stroke darts down a shaft of stainless steel which represents a lightning bolt. Sparks shoot up from the pool.

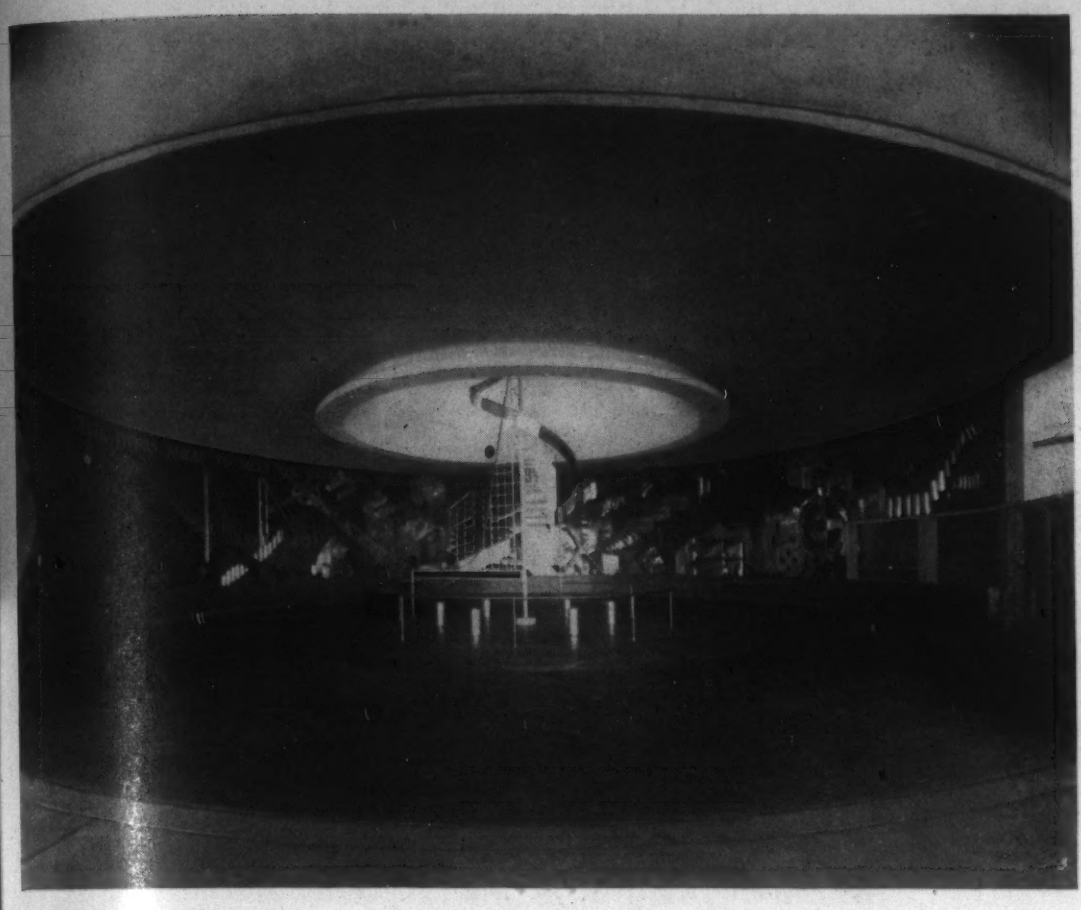
A View of the Statue of "Mercury" in the Front Facade of the Ford Pavilion. It is claimed to be the only steel figure of its kind—formed of bent stainless steel sheets, electrically welded. It is 25 ft. high, weighs 3 tons, and provides its own support by carrying its weight back from the shoulders to the draperies and thence to the building.



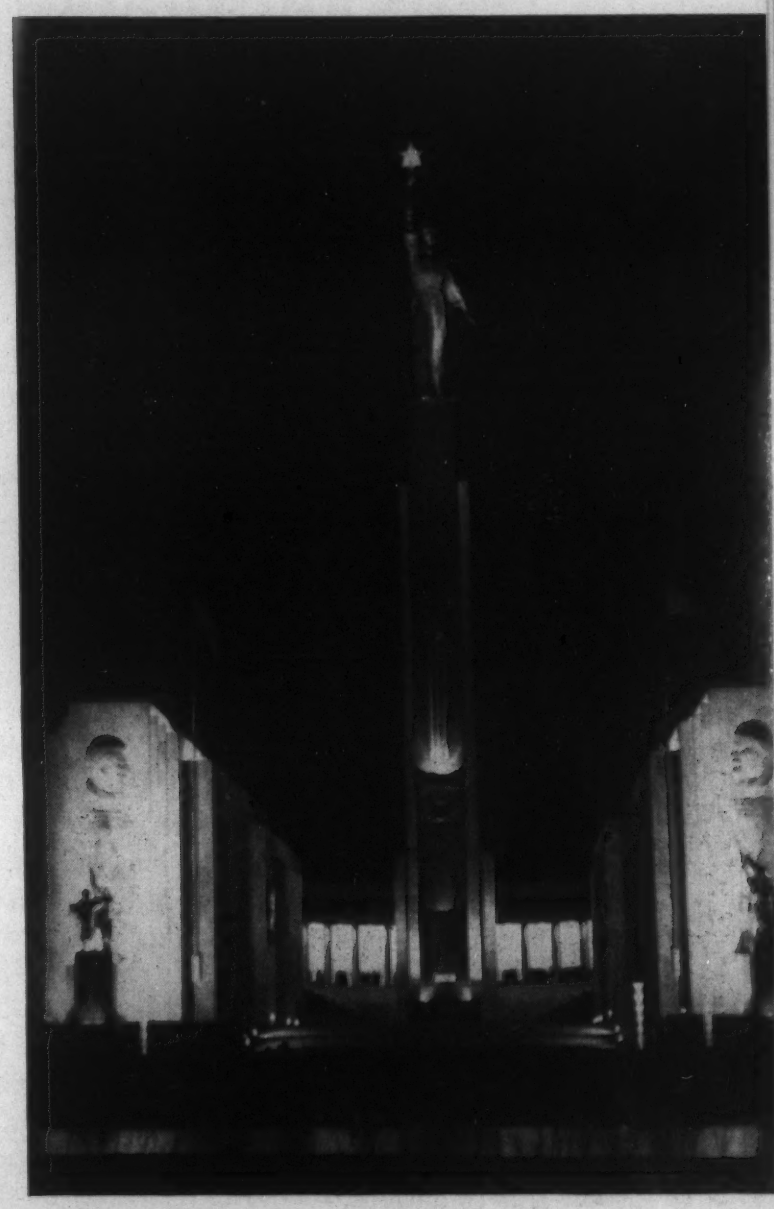
Part of the "Singing Tower," 120 ft. high, in front of the Exhibit Building of the Westinghouse Electric & Mfg. Co. Its use of pre-welded sections and self-closing rivet bolts is typical of the carefully planned engineering of this type of steel construction. The tower has six horizontal rings attached to a triangular steel pylon forming the face of the tower and housing lighting and sound equipment. The lowest tower ring is 18 ft. in dia., and the topmost 42 ft.

This Mural, in the Entrance Hall in the Ford Pavilion, is Claimed to be the First "Activated" Mural in the world. It is largely of metals and alloys and semi-glass, and many of its elements are animated.

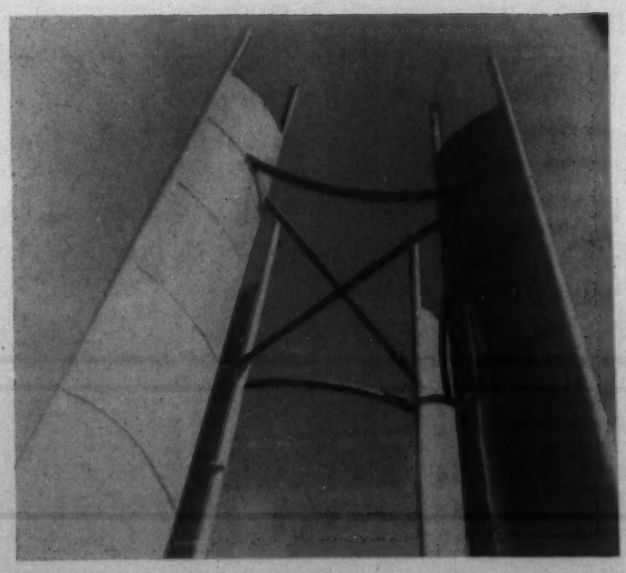
In this Mural—"Steel in Steel"—Adorning the Long Circular Wall around the Entrance Foyer of the United States Steel Subsidiaries Building, Thin Sheets of Steel are Hammered into Miniature Buildings, Bridges, Houses, Tractors, etc., and Mounted on a Background of Plain Blue Steel to Form a Panorama of Steel's Service to Civilization.



A Night View of the Russian Building. The statue on top of the tower is 60 ft. high and of stainless steel.



This Model Roller Bearing is a Feature of the Exhibit of the Timken Roller Bearing Co., Canton, Ohio, in the Metals Building. It measures 9 ft. 9 in. in diameter. It rolls back and forth at the top of the exhibit, showing how the parts of a bearing revolve in use. It is the central theme of an exhibit celebrating the 41st anniversary of roller bearings.



The Argentine Building is said to have more Aluminum in it than any Other. Four 80-ft. aluminum pylons (2 shown here) serve as flag poles. Each is 6 ft. 6 in. the long way and 2 ft. through, oval in form. They are built up on structural steel frames of T's and channels which are covered with aluminum sheets.

PART 2. CONCLUDED FROM MAY

Fatigue of Metals —Developments in the United States

by H. F. MOORE

Research Professor of Engineering Materials, University of Illinois, Urbana, Ill.

Effect of "Stress Raisers"

A considerable amount of experimental work has been done on the effect of notches, screw threads, grooves, keyways, fillets and holes on the fatigue strength of various metals. This study has been greatly aided by the development of the polarized light analysis of the theoretical stress distribution. This study of stress raisers has continued to emphasize the fact that, for high localized stress, the fundamental assumptions of the theory of elasticity do not hold and, as fracture is a highly localized phenomenon, the fatigue strength developed is practically always higher than that which would be indicated by application of the theory of elasticity. This is probably due to redistribution of stress and change of properties of material due to plastic action, aging, and cold work.

Peterson[14] and his fellow workers at the Westinghouse laboratories have published a considerable amount of experimental data and suggest that the stress gradient (suggested by Horger also) from maximum stress toward smaller stresses may be a vital factor and that grain size may play an important part, at least in steel.

Moore and Jordan[15] have suggested that the effect of a notch in a shaft might be expressed in terms of its theoretical effect, modified by an expression which involves the geometrical radius at the root of a notch, the diameter of the shaft, and the depth of the notch.

Several investigators have studied the strengthening of steel at points of concentrated stress by means of cold work. Results have shown distinct promise in this direction. (Horger[16]).

Fatigue Damage by Occasional Overstress

As engineers and metallurgists have studied fatigue failures which have occurred in service, the question has become more and more insistent whether most fatigue failures are caused by millions of repetitions of ordinary working stresses or by thousands of occasional overstresses. One of the major recent contributions to fatigue study in this country is that of French,[17] who studied the reduction of the original fatigue strength of metal caused by repetitions of stresses above the original endurance limit—repetitions not numerous enough to cause fracture or to start a detectible fatigue crack. By his method a "probable damage line," somewhat to the left hand of the ordinary S-N diagram, could be located. Paired values of stress and number of cycles below or to the left of this damage line indicate no damage to the metal as shown by reduced endurance limit; paired values to the right and above this line indicate damage. Following French's general scheme, Kommers[18] and Russell and Welcker[19] have reported several series of tests in which metal has been overstressed for a few thousand cycles, then understressed for a million or two cycles, with the result that at the end of this process the endurance limit of the metal was *higher* than that of the original unstressed metal.

Detection of Early Stage of a Fatigue Crack

A problem of no small practical importance is that of detecting fatigue cracks before they have spread so far that fracture of a structural or machine part is imminent. Most fatigue cracks start on or very near the surface of the metal, and direct examination or examination with a low-power microscope can sometimes be used to detect these cracks. A method in common use today for steel parts consists of magnetizing the surface to be examined and then sprinkling on it finely divided iron dust. At a crack there is a tendency to form a pair of magnetic poles and for iron dust to gather along the line of the crack. In this country the names of Rawdon[20] and of De-Forest[21] are prominent in connection with this development. We do not know the exact stage at which repeated intra-crystalline slip along planes of atomic weakness develops a spreading crack. When direct examination, or the use of iron dust, reveals a crack on the surface, or when X-rays, or a distorted magnetic field (Sperry),[22] reveal an internal crack, then the crack is well on its way to cause final fracture, and its rate of growth will be accelerated if it is allowed to continue.

Investigators are seeking more delicate methods of detecting an incipient fatigue crack, and there is some faint hope that the effect of a crack on the wave form or the damping of vibrations in the metal may

furnish a more delicate means of study of this crack formation. The detection of an incipient crack by reflection of sound waves from the walls of the crack is also under study. X-ray diffraction studies of crack formation are discussed in another section.

Effect of Chemical Composition

Just how important is the question of chemical composition of metals in judging their fatigue-resisting properties? Doubtless it is very important, but it is quite evident that knowledge of chemical composition alone does not give adequate information. The mere presence of a desirable chemical constituent by no means assures good fatigue-resisting properties, heat treatment and mechanical treatment may be equally important. And, speaking of heat treatment, it is well to remember that in the process of making and fabricating, steel and all other metals are always "heat treated."

One situation in which homogeneity of chemical composition is important is found in a tendency for decarburization in the surface of high carbon steel. Wire, axles, rails and other parts sometimes have their fatigue strength rather materially weakened by such decarburization. In such cases tests on rotating-beam specimens usually do not show this damage. The reduced section of these specimens goes below the decarburized layer. Decarburization can be detected by localized chemical analysis, or, usually, by the appearance of micrographs.

Metallography and Mechanical Properties

In connection with the study of fatigue of metals in the United States there have arisen many problems of correlation of fatigue strength with metallographic structure. These problems are all difficult. How can the qualitative indications of metallographic structure be correlated with the quantitative indications of mechanical tests? So apparently simple a problem as the correlation of grain size with strength and ductility has proved quite puzzling. What do we mean by grain size? Is it the size of grains seen in the ordinary micrograph, or is it the size of austenite grains in steel? May it be that, in low-carbon steel, it is ferrite grain size that is most significant, while the austenite or the pearlite grain size is most significant for medium-carbon steel? What is the important grain size for copper alloys, nickel alloys, aluminum alloys, magnesium alloys? What of the *shape* of grains? How important are the changes which take place as the metal "ages"? Questions, not even tentative conclusions, but here as elsewhere they demand study.

Judged by results of actual use, the qualitative results of metallographic examination may indicate desirable or undesirable grain structures for metals. It is, however, a task of very great difficulty to find any workable correlation between these qualitative results and the quantitative results which are found by mechanical tests. One of the most promising and most difficult fields of engineering research lies in the attempt to correlate metallography, chemical analysis, mechanical tests and service results when judging of the acceptability of metal for a particular service, or when assigning allowable stresses for design problems.

Study of Fatigue Failure by X-Ray Diffraction

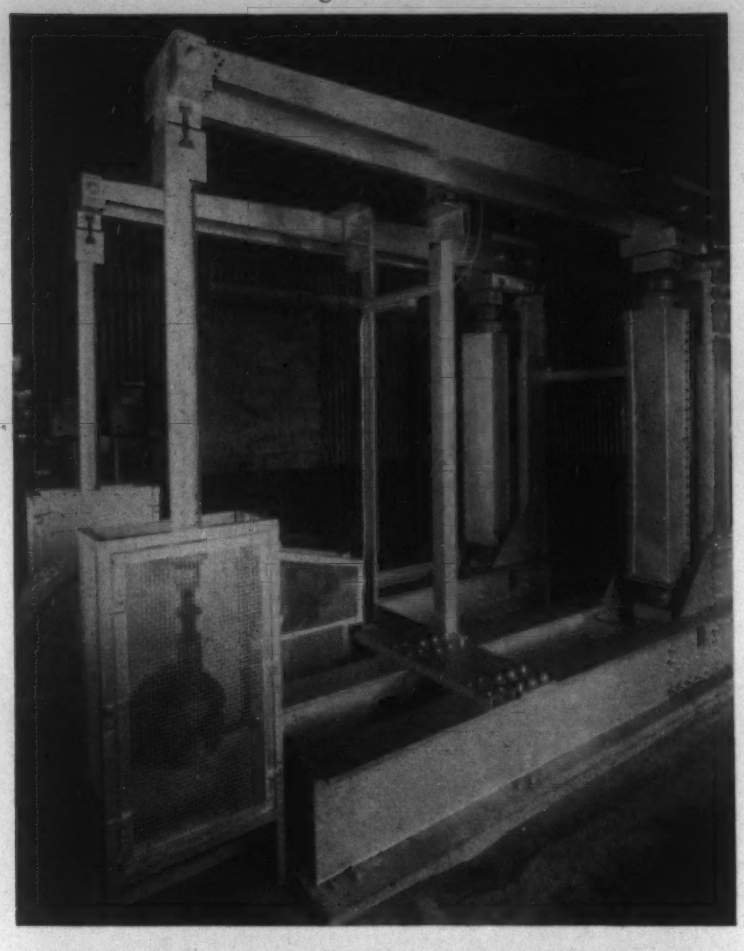
In this country considerable work has been done along this line especially by Barrett.[23] He has found, as have European investigators, that there is evidence of a gradual fragmentation of crystalline grains under repeated stress but has not been able to detect at all closely the actual beginning of a spreading fatigue crack. This still seems to be a matter of uncertainty and appears to depend upon conflicting factors such as strengthening by cold work or aging, reduction of effective ductility by the same processes, and readjustment of stress distribution by plastic action. The start of an actual spreading crack seems to be the resultant of several conflicting factors, and no technique for its detection can be laid down at present.

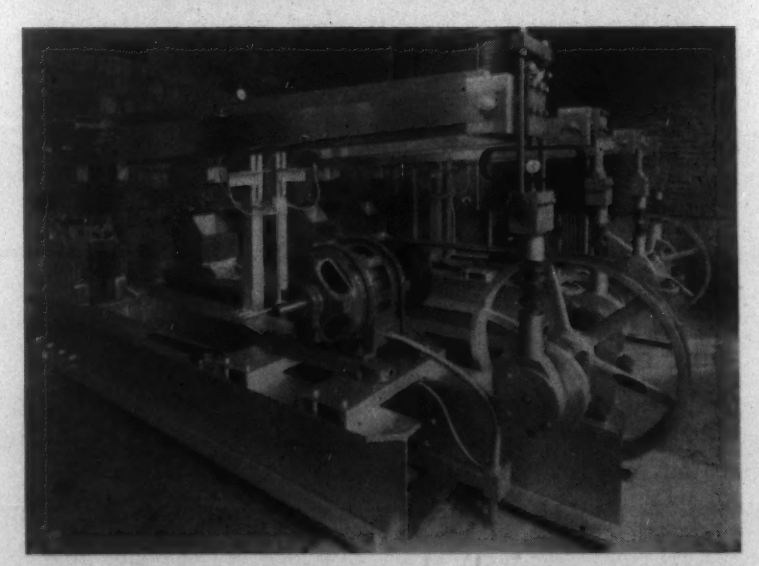
Endurance Limit and Cycles of Stress

In the case of some structural and machine parts, for example, railway bridge parts, welded structural parts and steam boiler plates, the number of cycles of stress which may be expected during a normal term of service is measured by the thousands rather than by the millions. It seems that the endurance limit determined for a comparatively small number of cycles of stress would be of significance for such structures. The determination of such an endurance limit can then be made on testing machines running at comparatively low speed, and using specimens large enough to show the effect of surface conditions and to include welded or riveted joints. In the case of boilers and other pressure vessels tests may be run on specimen test shells, using cycles of hydrostatic pressure.[24]

In such tests of structural and machine parts the value of the limiting number of cycles of stress used should be clearly stated, as, indeed, should be the case in all fatigue tests. This number of limiting cycles should be much larger, perhaps ten times larger, than the number of cycles of stress which may be expected in the normal "life" of the structure or machine. The reason for this is that, for stresses just above the endurance limit, a very slight change in stress causes a large change in the number of cycles of stress required for fracture, and the "factor of uncertainty" for number of cycles of stress for fracture is very large. In some recent tests of joints in structural members[11] the endurance limit for 2,000,-

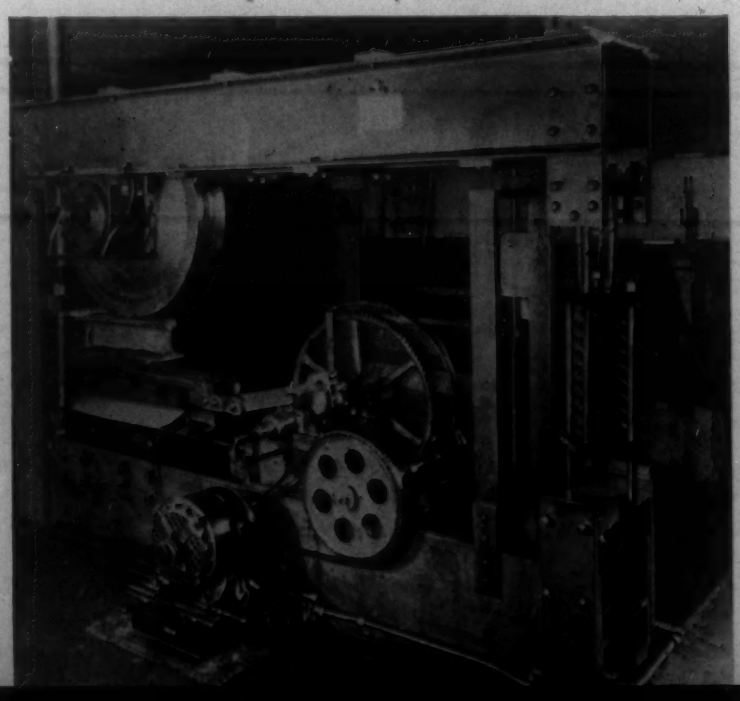
Fatigue Testing Machine for Columns, Beams and Frames. Maximum loading range on specimen ±50,000 lb. (Courtesy: American Society for Testing Materials.)





High-Speed Fatigue Machine for Joints. Maximum loading range on specimen ±50,000 lb. Speed 300 or 500 Cycles per Min. (Courtesy: American Society for Testing Materials.)

"Rolling-Load" Fatigue Testing Machine for Full-Section Specimens of Railroad Rail.



000 cycles of stress was determined. This number of cycles has been used for fatigue tests of railroad rails, while in some tests of pressure vessels the endurance limit for 800,000 cycles of stress was considered significant.

Speed of Stress Travel and Fatigue Strength

The relation of "impact" to "fatigue" has always been an intriguing study in this country as elsewhere. The importance of study of effect of rate of stress travel is becoming more apparent as engineers come into contact with practical problems in which velocities of parts are so great or paths of stress travel are so long that the fact that stress travels through a material with the velocity of sound in that material (about 17,000 ft. per sec. in steel) becomes of significance. The stress distribution in such a part may be quite different from that computed on the basis of the common "static" formulas.

Two examples may be cited: (1) Stresses set up in steam turbine discs by the lateral vibrations at certain critical speeds, and (2) failures observed in very long drill rods in the oil fields. The first of these problems was treated by mathematical analysis and check experiments by the late Wilfred Campbell,[25] and I recommend the study of his monograph, published by the General Electric Co. The second problem, so far as I know, has yet to be investigated, but it is not difficult to picture maximum stresses set up by the interference of reflected waves of stress traveling up and down a 3000-ft. drill rod—a maximum stress which would have very little relation, either in magnitude or location, to the maximum stress determined by our ordinary "static" system of stress analysis.

Our common texts on strength of materials handle the question of rapidly applied load on the assumption that such a load, while it may produce results differing in magnitude from a slowly applied load, will cause the stress-deformed member to assume the same *kind* of a shape as will the slowly applied load. This is not so, and the error in this assumption of a "statically equivalent load" becomes serious as speeds of loading increase or as paths of stress travel grow longer.

But the modification of stress distribution under rapid loading is not all there is to this problem of "kinematics of stress." The *strength* of metals to resist structural damage is also affected by speed of loading (Do you not remember skating over thin ice which would not "hold" if you stood still on it)? The endurance limit, as determined for small specimens of steel, does not seem to be greatly affected up to about 8000 cycles of stress per min. At some higher rates of stress application, the fatigue strength seems to be increased. What effect does size of specimen have on this increase of strength? We do not know. However, for some time there has been evi-

dence that under very rapidly applied load, failure of material may be of quite a different character from the failure under slowly applied load.[26] It is not difficult to picture the tensile stresses in a metal getting in their destructive work of fracture before the slower moving shearing stresses can get in their work of absorbing energy by non-fracturing slip. Of course this is a crude and somewhat speculative picture of the action of stress under rapidly applied load, and questions of length of path traveled by stress waves, reflection of waves, and relative loss of energy under shearing stress and tensile stress will be factors in determining stress distribution and structural damage.

Are Perfectly Elastic Metals Desirable?

One of the outstanding results of study of fatigue of metals is the realization of the importance of "stress raisers"—notches, holes, keyways, screw threads. Another result, not quite so outstanding but equally important in our thinking, is the fact that different metals are weakened by different amounts by these stress raisers. This is contrary to the effect which is predicted by the mathematical theory of elasticity, with its assumption of perfectly homogeneous and isotropic metal, and leads to the necessity of recognizing the limitations of that theory when applied to actual metals. This varying effect of stress raisers also raises the question which heads this section.

As Gough has shown,[27] localized inelastic action (shown by slip lines across crystalline grains) normally, and possibly universally, precedes the formation of a spreading crack. However, he and others have found again and again that localized, and even quite extensive, inelastic action may take place in some metals *without* the formation of a fatigue crack. It is not difficult to picture such metal as readjusting itself to localized stress inequalities by localized plastic yielding, and then "settling down" to a more nearly uniform stress distribution before the number of cycles of stress has become large enough to start a spreading crack. Then, as the number of cycles of stress increases, the improvement in stress distribution, due to the localized yielding, gives increased resistance to the starting of a spreading crack. In a perfectly elastic metal the "most stressed fiber" would continue to carry its unduly heavy share of the load until it fractured, then the next-highest stressed fiber would repeat the performance, then the next, and so on. This inelastic action in actual metals is very slight in extent; probably strains involved are of the order of 1 per cent over a minute area. For a discussion of this question of the desirability of a certain amount of inelastic action in metals subjected to repeated stress, I refer you to the American Society for Testing Materials, *Proceedings* for 1936, the Dudley Medal paper for that year by Swanger and Wohlgemuth on the failure of heat-treated steel wire in the cables of the Mt. Hope Bridge—a paper which every student of fatigue of metals should read.

Fatigue Testing in Special Fields

As fatigue testing becomes more and more common, its use is extended into special fields. Two such fields are wire testing and testing of welded joints. Space forbids any extensive discussion of these special fields in this paper. In the magazine *Wire and Wire Products* for May, 1937, is a summary of fatigue testing methods for wire and in the 1938 Handbook of the American Welding Society is a summary of fatigue testing methods for welded joints. Fatigue testing of springs is almost sure to be widely used in the future. Already in one laboratory (Trondley, Wm. D. Gibson Co.) some light springs are subjected to *acceptance* tests of 10,000,000 cycles of flexure. Doubtless other special fields will be developed.

Acknowledgments and References

In this paper references to certain American investigators have been made by name only. The writer realizes that other names of equal eminence might have been added. As pointed out in the opening paragraph, this paper presents the viewpoint of one investigator, and hence necessarily gives an incomplete picture. For sins of commission and especially for sins of omission, pardon is sought.

We look back with a smile on the simple days of 1919, when we felt that the main problem in fatigue of metals was the study of endurance limit—whether it existed, and, if it did, what relation it bore to the popular technical idol of that day, the "true" elastic limit. The path of research has not been so smooth as we foresaw, and, as so often is the case, the new questions raised have exceeded in number the conclusions reached. But what would be the fun in making a research that settled anything beyond the possibility of further research?

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Residual Metals in Open-Hearth Steel

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THIS IS THE SEVENTH of a series of articles on residual metals in open-hearth steel. As stated in previous articles[1] measurable amounts of copper, nickel, chromium, tin, arsenic, and antimony are found in practically all open-hearth steels. Other elements such as molybdenum and vanadium may be present in smaller amounts. Residual manganese and silicon are found in steels, but since they are intentionally added to the charge they should not be classed as truly residual constituents. Copper is present in some of the iron ores of the United States, and is found in pig iron made from such ores. It also enters steel through scrap such as bushings, wire, tubing, and from copper-bearing steel and iron scrap.

Most of the residual nickel probably comes from iron and steel scrap although a few foreign ores contain considerable nickel. Chromium comes largely from alloy steel scrap, but some iron ores contain appreciable amounts of this element. Tin comes from such sources as de-tinned scrap, cans, bearings, and galvanized scrap. Arsenic is found in small amounts in many iron ores and in larger quantities in some of the Southern United States and foreign ores. Antimony probably comes partly from non-ferrous alloys such as bushings and bearings that accompany ferrous scrap.

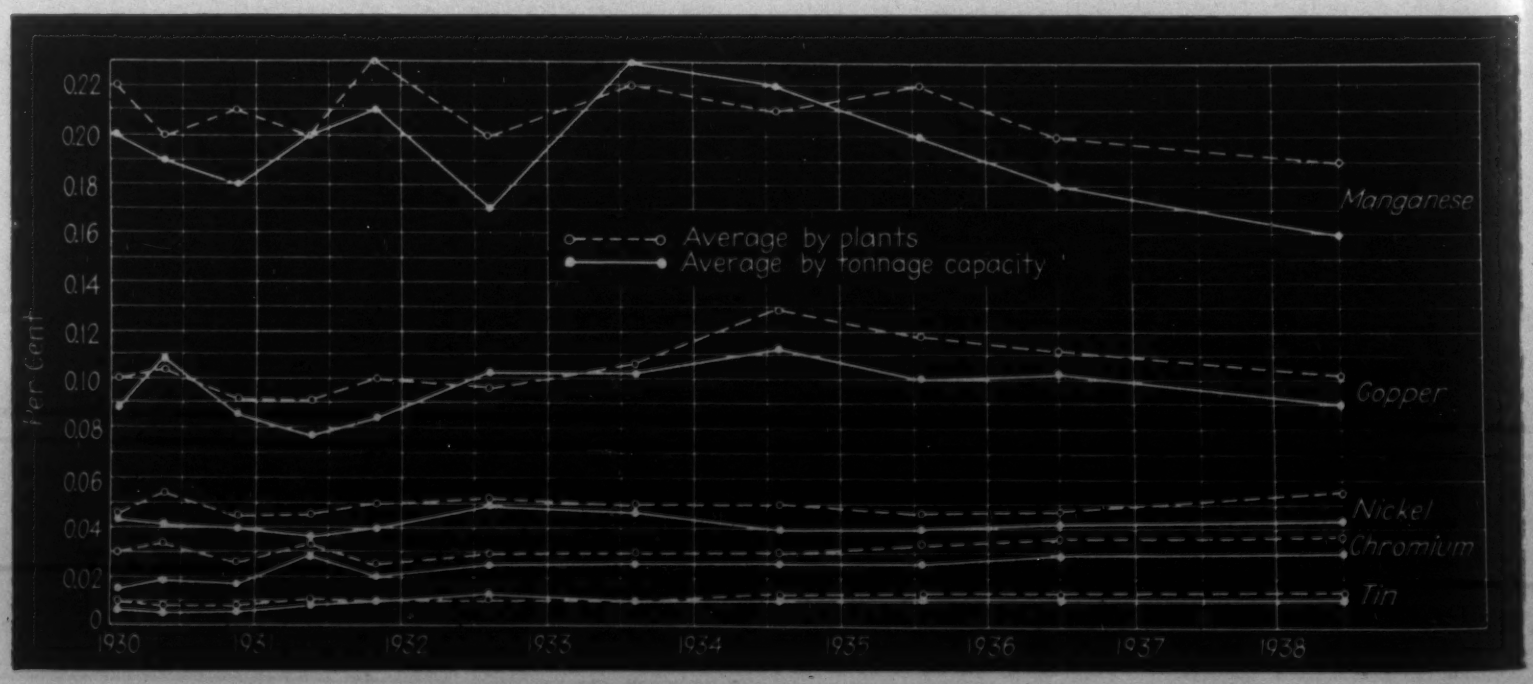
Virtually all of the copper and nickel in the blast furnace and open-hearth charges is recovered in the metal. In the open-hearth the recovery of chromium depends on oxidizing conditions, length of the refining period, slag composition, and carbon content of the steel. Probably nearly all the tin and a high percentage of both arsenic and antimony remains in the steel. Zinc is largely eliminated by volatilization and part of the lead volatilizes and part of it settles through the bath into or through the furnace bottom. Molybdenum is nearly all recovered but is present in small amounts. Vanadium remains in the steel to a large extent although partly as oxide.

Williams[2] has discussed the technical and economic importance of iron and steel scrap.

Data On Samples from Cooperating Companies

This report brings the data up to date. As stated in previous articles the cooperating steel plants in the United States and Canada take samples from representative heats before alloy additions are made; so the samples in general indicate the composition of the plain carbon base used in the various plants before adjustment of the composition by alloy additions. At the end of the month composite samples

Fig. 1—Average of All Plants, December, 1929 to December, 1938, inclusive.



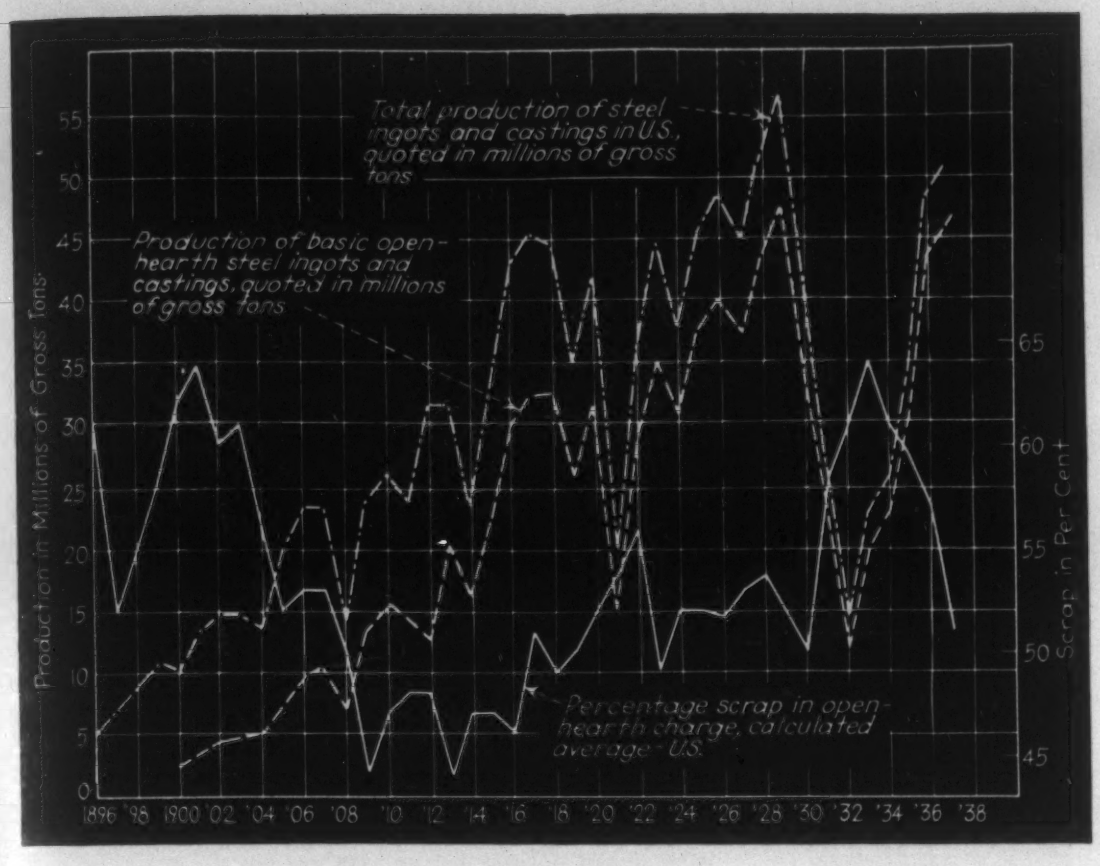


Fig. 2—Showing Relationship Between Scrap Ratio in Charge and Total Steel Production.

are made and sent to Battelle Memorial Institute where annual composite samples are made for analysis. Samples were not analyzed for the year 1937; so no report was made for that year. During 1938, 18 plants with a normal tonnage capacity of 8,200,000 tons cooperated.

Fig. 1 shows graphically the average percentage of residual metals for all plants from December, 1929, to December, 1938, inclusive. Analyses are reported for nickel, copper, tin, chromium, and manganese. Results are given for the arithmetic mean of all plants and also for the weighted average based on normal annual tonnage capacity. The average of all plants for any period refers to those plants that cooperated in the period. The year is plotted as the middle of the period represented. Analyses reported in Fig. 1 were made at the Pittsburgh Station of the U. S. Bureau of Mines until March 1931, and at Battelle Memorial Institute since that time.

Data on residual arsenic and antimony were given in the 1936 paper.

The results of individual plants from March, 1931, to December, 1938, inclusive, are given in the Table. Samples from plants B, D, E, K, and M were analyzed both by chemical and spectroscopic methods for lead. In no case was as much as 0.001 per cent Pb found.

During the 10-yr. period of this investigation, increases in residual metals for the most part have been negligible, and there would appear to be no danger in their getting out of control in the near future. It has been decided, therefore, to recess this study for a period of about 5 yrs. at which time samples can again be taken and analyses made.

Table of Residual Metals in Open-Hearth Steel March 1931—December 1938, Inclusive

Plant No.	1931 Mar.-July	1931-1932 Aug.-Jan.	1932-1933 Feb.-Jan.	1933-1934 Feb.-Jan.	1934-1935 Feb.-Jan.	1935 Feb.-Dec.	1936 Jan.-Dec.	1938 Jan.-Dec.
				Nickel, Per Cent				
A	0.039	0.063	0.109	0.074	0.115	0.048	0.071	0.098
B	0.021	0.024	....	0.013	0.016	0.015	0.021	0.022
C	0.043	0.054	0.054	0.033	0.040	0.036	0.034	0.031
D	0.039	0.035	....	0.070	0.091	0.091	0.090	0.086
E	0.089	0.071	0.055	0.050	0.074	0.053	0.068	0.067
F	0.032	0.072	0.057	0.057	0.057	0.045	0.047	0.059
G	0.041	0.037	0.037	0.029	0.039	0.053	0.064	0.088
H	0.071	0.060	0.062	0.052	0.051	0.052	0.050	0.032
I	0.008	0.030	0.027	0.023	0.023	0.031	0.025	0.028
J	0.021	0.038	0.041	0.161	0.047	0.044	0.047	0.051
K	0.019	0.031	0.049	0.036	0.027	0.043	0.049	0.035
L	0.053	0.039	0.048	0.030	0.044	0.032	0.028	0.031
M	0.039	0.034	0.042	0.062	0.038	0.034	0.038	0.075
N	0.041	0.040	0.043	0.017	0.013	0.033	0.036	0.029
O	0.063	0.083	0.068	0.077	0.086	0.073	0.065	0.103
P	0.082	0.107	0.087	0.079	0.075	0.051	0.054	....
Q	0.057	0.050	0.047	0.047	0.039	....	....	....
R	0.063	0.044	0.060	0.051	0.049	0.071	0.066	0.069
T	....	....	0.036	0.032	....	0.037	0.028	0.044
S	....	....	0.039	0.030	....	....	0.018	....
U	....	....	0.040	0.043	....	....	0.057	....
V	....	....	....	....	....	....	0.038	0.038
				Copper, Per Cent				
A	0.025	0.045	0.051	0.061	0.058	0.050	0.067	0.045
B	0.022	0.044	....	0.059	0.056	0.044	0.037	0.036
C	0.097	0.215	0.218	0.150	0.196	0.200	0.181	0.148
D	0.104	0.053	....	0.173	0.218	0.232	0.218	0.218
E	0.268	0.296	0.193	0.234	0.318	0.279	0.222	0.254
F	0.106	0.080	0.080	0.114	0.118	0.086	0.103	0.089
G	0.030	0.015	0.015	0.040	0.049	0.050	0.050	0.046
H	0.075	0.077	0.097	0.101	0.126	0.109	0.103	0.064
I	0.059	0.074	0.069	0.077	0.077	0.083	0.086	0.081
J	0.049	0.062	0.050	0.041	0.091	0.085	0.097	0.121
K	0.076	0.084	0.120	0.104	0.124	0.087	0.098	0.047
L	0.075	0.077	0.083	0.094	0.075	0.075	0.082	0.079
M	0.117	0.085	0.098	0.099	0.083	0.079	0.066	0.068
N	0.065	0.113	0.085	0.115	0.093	0.108	0.090	0.108
O	0.202	0.215	0.182	0.269	0.281	0.224	0.240	0.230
P	0.088	0.138	0.122	0.098	0.150	0.146	0.162	....
Q	0.122	0.114	0.116	0.129	0.135	....	....	....
R	0.040	0.032	0.061	0.082	0.078	0.115	0.107	0.064
T	....	....	0.054	0.059	....	0.068	0.043	0.033
S	....	....	0.056	0.077	....	....	0.067	....
U	....	....	0.058	0.058	....	....	0.059	....
V	....	....	....	....	....	....	0.169	0.125

Plant No.	1931 Mar.-July	1931-1932 Aug.-Jan.	1932-1933 Feb.-Jan.	1933-1934 Feb.-Jan.	1934-1935 Feb.-Jan.	1935 Feb.-Dec.	1936 Jan.-Dec.	1938 Jan.-Dec.
			Tin, Per Cent					
A	0.004	0.003	0.004	0.004	0.007	0.003	0.005	0.005
B	0.007	0.008	....	0.007	0.005	0.005	0.006	0.007
C	0.017	0.025	0.034	0.016	0.006	0.022	0.021	0.016
D	0.011	0.008	....	0.019	0.024	0.029	0.024	0.028
E	0.035	0.041	0.021	0.028	0.041	0.038	0.027	0.048
F	0.014	0.013	0.014	0.013	0.012	0.012	0.014	0.012
G	Nil	0.003	0.005	0.004	0.005	0.005	0.006	0.006
H	0.011	0.017	0.012	0.014	0.014	0.016	0.012	0.010
I	0.008	0.006	0.005	0.009	0.008	0.010	0.010	0.009
J	0.003	0.006	0.006	0.004	0.011	0.011	0.014	0.017
K	0.008	0.012	0.014	0.011	0.011	0.011	0.013	0.011
L	0.007	0.006	0.013	0.014	0.010	0.012	0.014	0.011
M	0.008	0.009	0.010	0.008	0.006	0.008	0.006	0.010
N	0.008	0.008	0.011	0.010	0.018	0.024	0.024	0.018
O	0.020	0.017	0.018	0.025	0.025	0.031	0.028	0.030
P	0.009	0.015	0.017	0.011	0.015	0.018	0.019	....
Q	0.021	0.022	0.018	0.023	0.023	....	....	....
R	0.005	0.004	0.008	0.008	0.008	0.016	0.015	0.009
T	....	....	0.006	0.005	....	0.006	0.003	0.005
S	....	....	0.007	0.007	....	....	0.006	....
U	....	....	0.007	0.006	....	....	0.006	....
V	....	....	....	....	....	....	0.017	0.018
			Manganese, Per Cent					
A	0.22	0.24	0.23	0.21	0.25	0.20	0.21	0.20
B	0.23	0.23	...	0.39	0.39	0.19	0.14	0.11
C	0.11	0.11	0.10	0.12	0.10	0.11	0.12	0.09
D	0.21	0.24	...	0.27	0.18	0.37	0.22	0.15
E	0.11	0.24	0.12	0.12	0.13	0.17	0.16	0.12
F	0.15	0.16	0.14	0.16	0.16	0.16	0.14	0.15
G	0.35	0.46	0.42	0.38	0.40	0.39	0.36	0.40
H	0.12	0.11	0.10	0.12	0.12	0.10	0.12	0.13
I	0.10	0.08	0.06	0.08	0.10	0.11	0.11	0.10
J	0.27	0.48	0.22	0.24	0.25	0.25	0.26	0.27
K	0.12	0.13	0.14	0.14	0.14	0.12	0.15	0.15
L	0.26	0.24	0.27	0.24	0.27	0.33	0.33	0.27
M	0.25	0.24	0.20	0.19	0.22	0.18	0.18	0.19
N	0.16	0.16	0.14	0.17	0.16	0.14	0.13	0.14
O	0.19	0.18	0.18	0.19	0.14	0.17	0.18	0.18
P	0.24	0.24	0.23	0.25	0.25	0.26	0.20	...
Q	0.25	0.23	0.21	0.21	0.20	...	...	...
R	0.26	0.31	0.30	0.31	0.27	0.31	0.31	0.31
T	...	...	0.28	0.32	...	0.36	0.29	0.34
S	...	...	0.32	0.36	...	...	0.33	...
U	...	...	0.07	0.07	...	...	0.07	...
V	...	...	...	...	...	...	0.11	0.14
			Chromium, Per Cent					
A	0.048	0.031	0.040	0.040	0.038	0.052	0.064	0.049
B	0.024	0.019	....	0.008	0.007	0.006	0.004	0.008
C	0.020	0.019	0.028	0.029	0.029	0.024	0.034	0.020
D	0.030	0.019	....	0.041	0.039	0.038	0.044	0.052
E	0.052	0.036	0.033	0.038	0.036	0.052	0.042	0.043
F	0.031	0.026	0.029	0.030	0.030	0.036	0.038	0.030
G	0.044	0.038	0.040	0.038	0.035	0.045	0.056	0.071
H	0.029	0.030	0.028	0.030	0.033	0.036	0.031	0.028
I	0.012	0.012	0.013	0.012	0.012	0.017	0.030	0.017
J	0.021	0.021	0.021	0.025	0.031	0.036	0.045	0.049
K	0.025	0.011	0.025	0.035	0.032	0.022	0.030	0.034
L	0.033	0.022	0.027	0.032	0.030	0.031	0.032	0.033
M	0.023	0.006	0.010	0.022	0.020	0.015	0.025	0.027
N	0.034	0.031	0.034	0.027	0.029	0.024	0.032	0.021
O	0.049	0.036	0.041	0.041	0.037	0.057	0.061	0.071
P	0.049	0.030	0.038	0.034	0.034	0.049	0.040	....
Q	0.049	0.046	0.045	0.039	0.037	....	....	....
R	0.021	0.021	0.023	0.029	0.031	0.041	0.041	0.057
T	....	....	0.028	0.028	....	0.040	0.020	0.040
S	....	....	0.030	0.040	....	....	0.027	....
U	....	....	0.022	0.027	....	....	0.040	....
V	....	....	....	....	....	....	0.031	0.024

Use of Scrap In Open-Hearth Furnaces

The curves in Figs. 2 and 3 have been plotted to show the variation in the amount of scrap used in the various years and to permit comparison of this with prices and production rates. Scrap percentages were obtained by calculation from statements of basic pig iron and basic open-hearth steel production contained in the annual statistical reports of the American Iron and Steel Institute. In determining the percentage of scrap used, it was assumed that: (1) an ingot recovery of 88 per cent of the metal charged was made, (2) metallic addition agents equivalent to 1 per cent of the charge were used, and (3) iron ore containing 50 per cent of recoverable iron was used to the extent of 5 per cent of the pig iron charged. As used in this report, the percentage of scrap is taken as the percentage of scrap in scrap plus pig iron.

Fig. 3 shows the relation between scrap in the charge and prices of pig iron and scrap.

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[1] Clyde E. Williams and John D. Sullivan. "Residual Metals in Open-Hearth Steel." METALS AND ALLOYS, Vol. 3, 1932, page 240.

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[2] Clyde E. Williams. "The New Technical and Economic Importance of Iron and Steel Scrap." Yearbook of the American Iron and Steel Institute, Vol. 26, 1936, page 185.

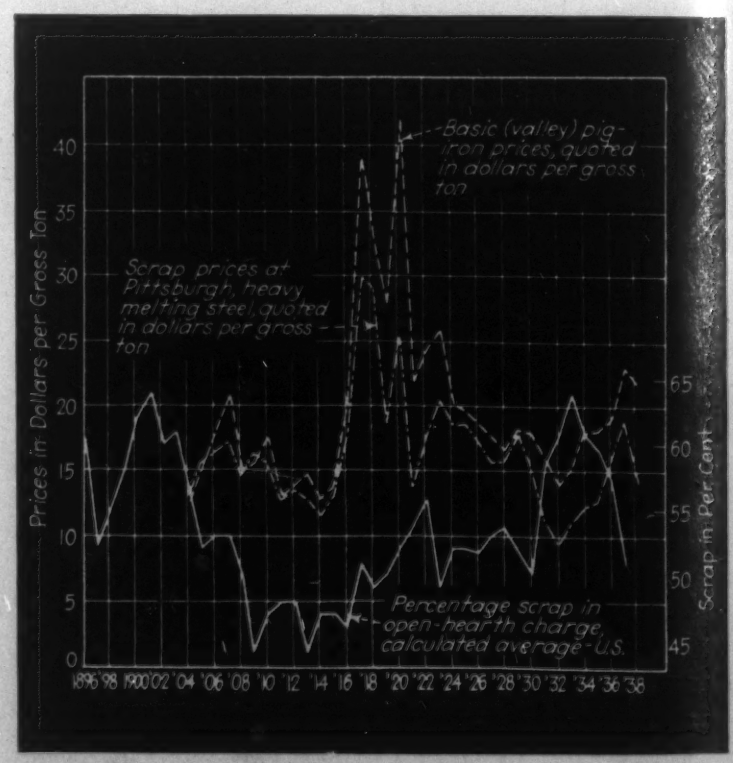


Fig. 3—Showing Relationship Between Scrap Ratio in Charge and Prices of Pig Iron and Scrap.

Anodically Oxidized Aluminum Alloys — Metallographic Examination

by F. KELLER and G. W. WILCOX

Metallurgical Division, Aluminum Research Laboratories, New Kensington, Pa.

Protective oxide coatings on aluminum and its alloys are formed by making the article the anode in a suitable electrolyte such as sulphuric, chromic or oxalic acid.

Just what becomes of the various elements and constituents in aluminum alloys when anodically treated is a subject of great interest. METALS AND ALLOYS *is publishing for the first time the results of an extensive investigation conducted by the Aluminum Research Laboratories in this and a second article. The title of the second is "Behavior of Alloy Constituents in the Anodic Coating of Aluminum."*

The two articles are in the nature of a continued story. It is pointed out that a number of useful methods of examining these coatings were developed and it is believed the two articles will attract considerable attention.—The Editors.

THE WIDESPREAD USE of the electrolytic oxidation process for coating aluminum alloys to obtain improved resistance to abrasion and corrosion and a pleasing surface finish has led to several investigations of the effect of the oxidation process on the different types of commercial aluminum alloys. With the oxidation process, such specific characteristics of the oxide film as appearance, uniformity, color, density and porosity are related to the type of alloy, the temper of the alloy, the electrolyte employed and the coating conditions.

The electrolytes employed commercially for the production of anodic coatings contain sulphuric acid or chromic acid. The most generally used process in this country employs an electrolyte containing sulphuric acid; it is known as the Alumilite Process (patented by the Aluminum Co. of America). In the formation of oxide coatings on aluminum alloys, the fundamental reaction is the oxidation of the metallic surface to aluminum oxide.

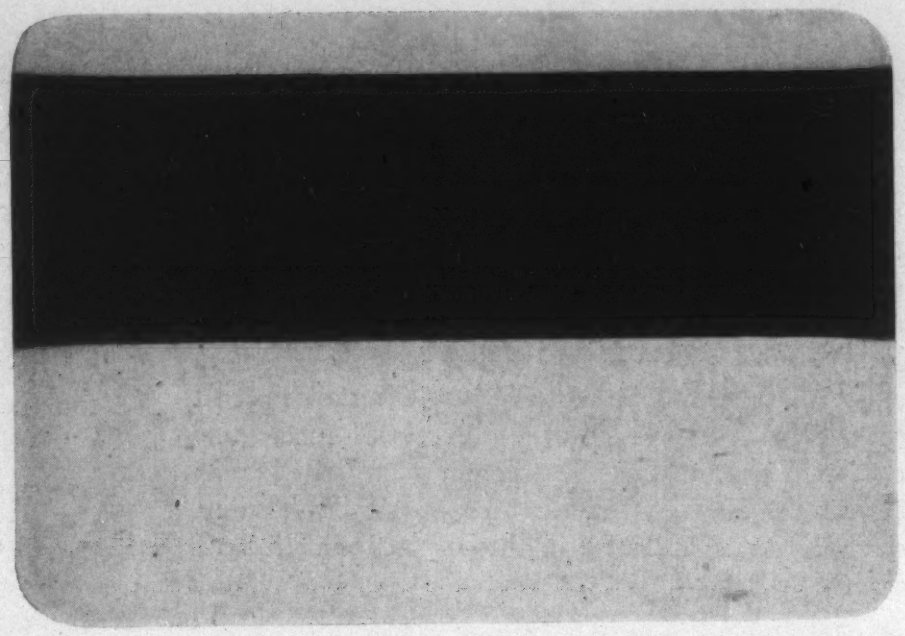
Previous work by Fischer,[1] Brenner and Vogel,[2] Röhrig and Käpernick[3] and Keller, Wilcox, Tosterud and Slunder[4] has indicated the importance of a fundamental knowledge of the effects of the anodic oxidation treatment on the different micro-constituents and of the effects of various metallurgical conditions on the results obtained in the anodic oxidation of commercial alloys.

Methods for Examination of Oxide Coatings

It has been recognized for some time that many of the characteristics of oxide coatings can be studied to advantage by metallographic methods. In fact, one method[5] which has been used extensively comprises the examination of polished cross sections of anodically oxidized samples. It has been employed for determining the continuity and thickness of the oxide coating and the microstructural features of the basic material which might influence the oxidation characteristics. This method, also, was used for the determination of the behavior of constituents in the anodic oxidation of aluminum.[4] Cross sections of oxide coatings on aluminum do not reflect very much light back through the optical system of the microscope when they are examined under vertical illumination; consequently, these coatings appear as a narrow dark band in a light matrix. The amount of information which can be obtained by microscopic examination of oxidized samples by the usual metallographic methods is somewhat limited. It was necessary, therefore, to develop new methods of preparation to enlarge the scope of metallographic investigations. This article describes the results obtained on anodically coated samples of aluminum alloys by the use of these new methods.

The characteristic appearance, under the microscope, of cross sections of oxide coatings formed on

Fig. 1.—This Shows the Typical Appearance of a Cross Section through a sample of 99.95 per cent Aluminum Sheet Which had been Oxidized in a Sulphuric Acid Electrolyte for 2 hrs. The dark band at the top is the oxide coating on one surface of the sheet. Reflected light, vertical illumination. Unetched. 500X.



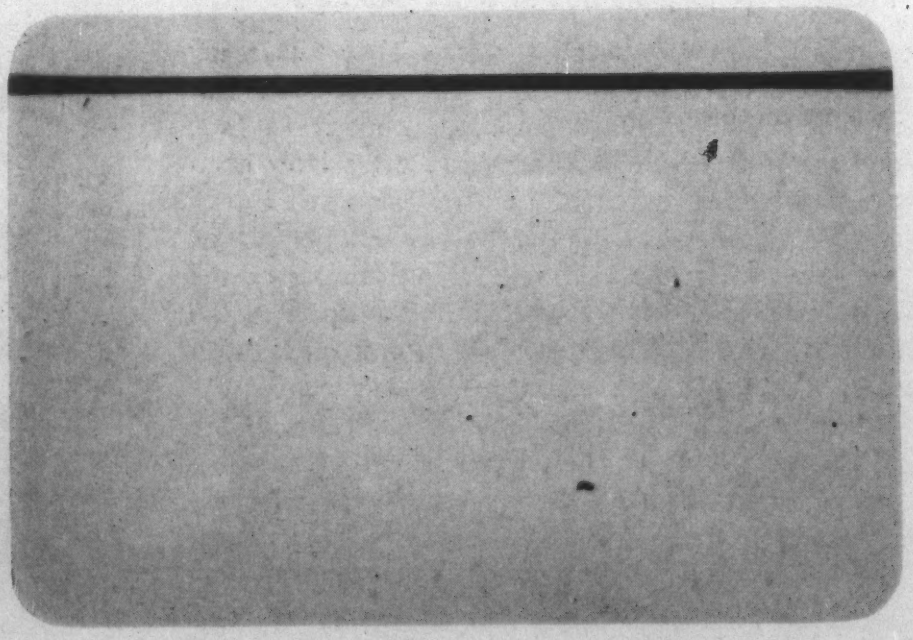


Fig. 2.—This Shows the Typical Appearance of the Oxide Coating on a Sample of the Same Material Which had been Oxidized in a Chromic Acid Electrolyte for 1 hr. Reflected light, vertical illumination. Unetched. 500X.

high purity aluminum sheet (99.95% Al) when examined by the usual metallographic methods is shown by Figs. 1 and 2. These samples were anodically oxidized in 15 per cent sulphuric acid and 9.5 per cent chromic acid respectively. Additional information about these oxide coatings can be obtained by using reflected polarized light.[6] With polarized light, it is possible to identify the anodic coating with respect to the type of electrolyte employed. Furthermore, it is possible, in some cases, to determine whether or not the oxide coating has received a sealing treatment as well as the type of sealing treatment.

As an example, the appearance of a cross section of an anodically oxidized 2S sheet sample is shown in Fig. 3 as it appears when examined by ordinary reflected light and in Fig. 4 when examined under polarized light with crossed polarizers. This particular sample had received two different anodic treatments. First, it was oxidized for 20 min. in sulphuric acid electrolyte, then it was oxidized for 30 min. in oxalic acid electrolyte. As a result, the sample bears two anodic coatings. The coating formed in the oxalic acid electrolyte is between the oxide coating formed in the sulphuric acid electrolyte and the surface of the aluminum sheet. The different optical characteristics of the oxide coatings formed in these two electrolytes are evident with polarized light and crossed polarizers. The change in appearance of these two oxide coatings resulting from a sealing treatment in boiling water is illustrated by Fig. 5. The characteristics of another sample with a double oxide coating are shown by Fig. 6. This sample was oxidized, first, in a sulphuric acid electrolyte and then in a chromic acid electrolyte.

Another method of preparing specimens of anodically coated aluminum in order to determine the effect of variations in microstructure comprises oxidizing the surface of a metallographic specimen which has been polished in the manner required for ordinary microscopic examination. Since the anodic coating on such a sample is ordinarily very smooth, the characteristics of the coating and the microstructure of the interface can be observed by examination of the surface of the oxidized specimen with the aid of either vertical or dark field illumination.

Illustrations of the microstructural characteristics of oxidized polished metallographic specimens with dark field illumination are included as Figs. 7 and 8. Examination of such specimens shows that the electrolyte used for the anodic treatment causes a slight etching attack on the constituents and matrix at the interface of oxide and metal and produces effects somewhat similar to those obtained with some of the reagents employed for etching. By this method, the microstructural features responsible for

streaks and variations in the appearance of the oxidized samples may be studied. These metallographic features revealed by the oxidation treatment can be duplicated substantially by etching a polished metallographic sample in a 25 per cent solution of sulphuric acid at 70 deg. C. for 2 to 3 mins.

A third method of preparing specimens of anodically coated samples for microscopic examination and one not hitherto used comprises the preparation of thin sections of the oxide coatings themselves in the manner that thin sections of rocks and minerals are made for petrographic examinations. Such thin sections can be examined by means of either ordinary or polarized transmitted light. The specimens are prepared by mounting the oxidized aluminum sample in molded Lucite in such a manner that the aluminum can be removed from the back of the oxide coating by grinding with metallographic emery papers until a suitable area of the oxide coating is exposed. Then, the exposed oxide is polished with 600 alundum flour and magnesium oxide until a smooth surface is obtained. Much information, not obtainable from ordinary polished metallographic samples, can be obtained by examination of these thin sections of the oxide coatings.

By the use of this method, it has been found that the oxide layer on an oxidized aluminum alloy has a definite microstructure and that this microstructure is related to the microstructure of the metal from which the coating was formed. From these results, it appears that anodic coating characteristics such as color, streaking and uniformity of surface appearance may be related to the uniformity of the microstructure of the oxide coating itself more than to an etching effect of the electrolyte on the metal surface at the interface.

Examples of the results obtained from thin sections of oxide coatings are illustrated by Figs. 9 to 19 inclusive. The microstructures typical of surface sections of three different aluminum alloys, namely, aluminum-silicon, aluminum-iron and aluminum-manganese, as they appear by ordinary metallographic examination before any oxidation treatment are shown in Figs. 9 to 11 inclusive. The structures of thin sections of the oxide coatings formed on these alloys in sulphuric acid electrolyte are shown in Figs. 12 to 14 as they appear when these sections are examined with reflected light and vertical illumination. For comparison, the microstructures of the same thin sections are shown in Figs. 15 to 17 inclusive as they appear when examined by means of light transmitted through the oxide coatings. From these illustrations, it is apparent that the oxide coatings on these alloys have definite microstructures and that these microstructures are related to those of the alloys from which the oxide coatings were formed. It is apparent also that some of the microconstituents remain in the oxide coatings in a sub-

Fig. 3. Shows the Oxide Coatings on 2S Sheet Oxidized in both Sulphuric and Oxalic Acid Electrolytes as They Appeared under Ordinary Light. Unetched. 500X.

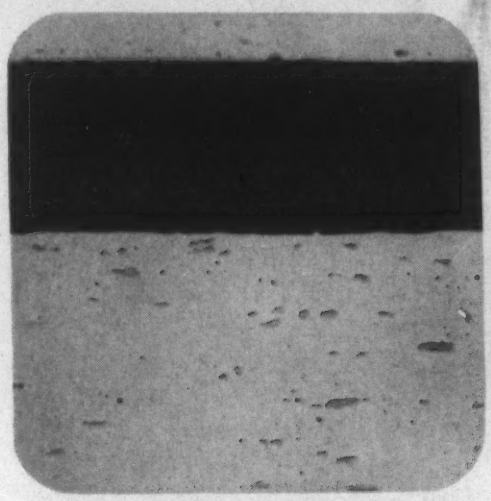
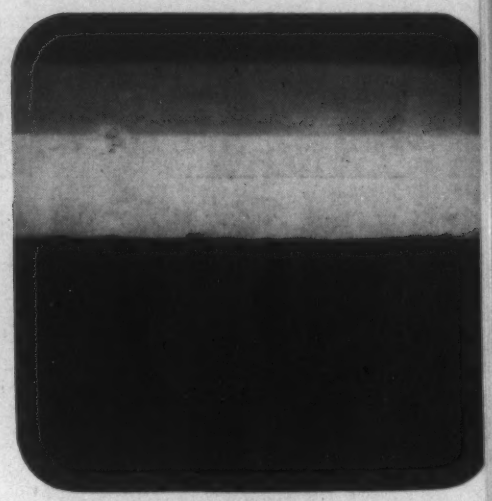


Fig. 4. This Shows the Appearance of the Same Coatings as in Fig. 3 as they Appeared under Polarized Light with Crossed Polarizers. Unetched. 500X.



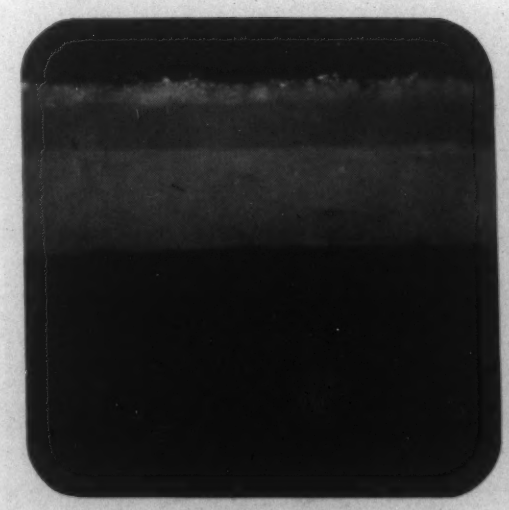


Fig. 5. This Shows the Change in Appearance of the Two Coatings in Fig. 4 Caused by a Sealing Treatment in Boiling Water. Polarized light. Unetched.

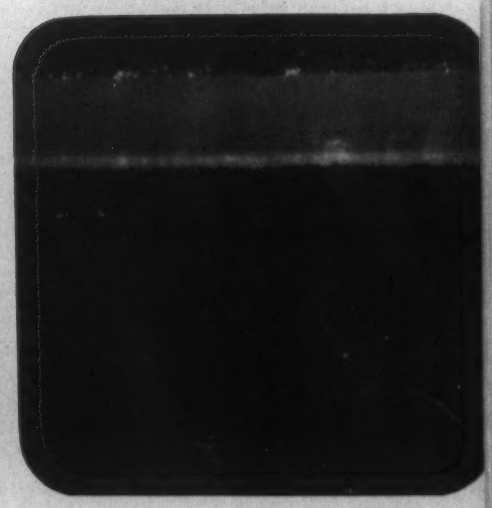


Fig. 6. This Shows the Oxide Coatings on 2S Sheet Which was Oxidized in both Sulphuric Acid and Chromic Acid electrolytes. Polarized light. Unetched. 500X.

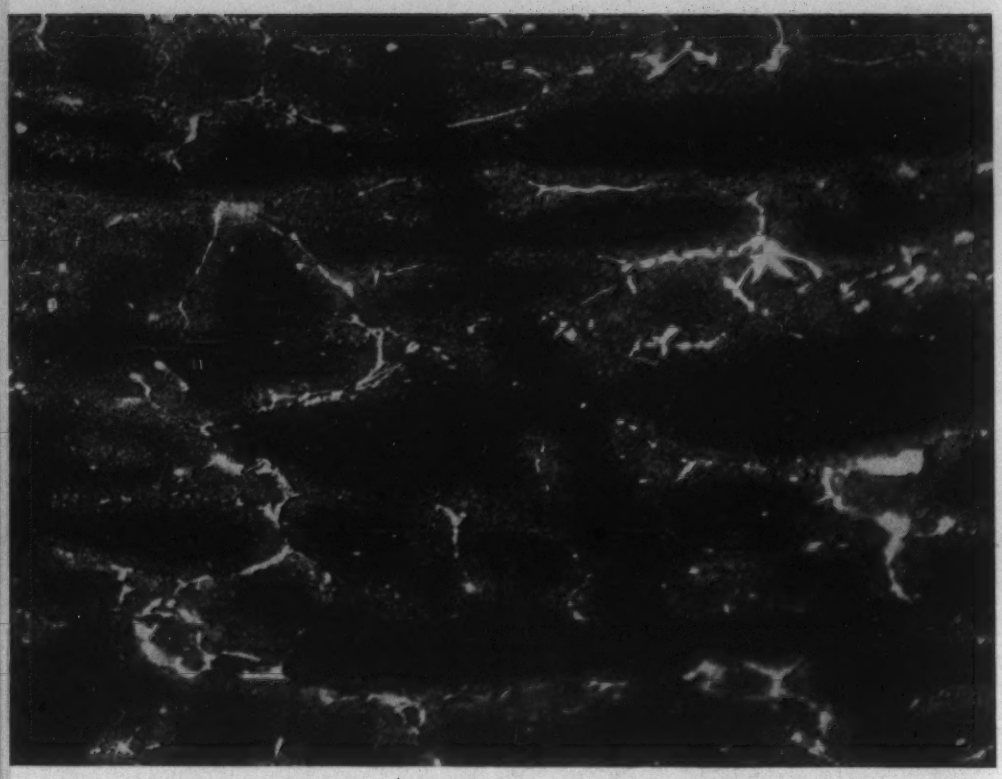


Fig. 7. This Shows the Microstructure of an Al-Mg-Zn Alloy Sample Which was Given a Metallographic Polish and Anodically Coated in a Sulphuric Acid Electrolyte. The structure shown is that of the oxidized surface as it appeared with dark field illumination. 100X.

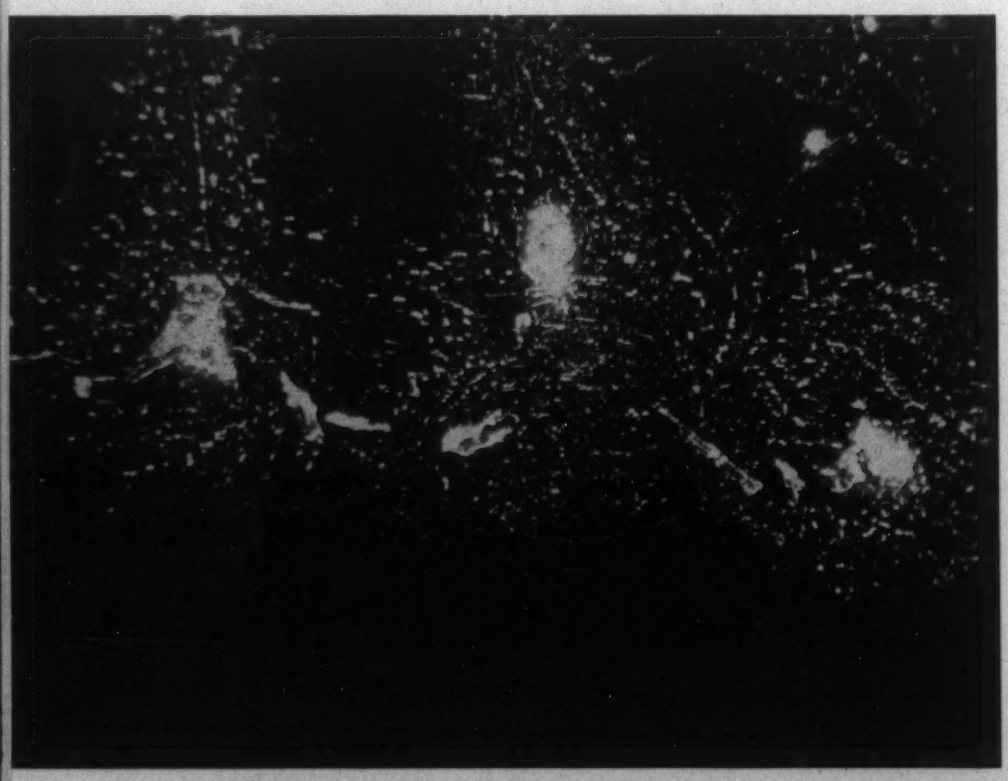


Fig. 8. This Shows at a Higher Magnification the Constituent Network and the Coring in the Above Sample Revealed by the Oxidation Treatment. Dark field illumination. 500X.

stantially unchanged condition.

Previous investigational work has shown that some constituents, such as silicon and Al-Mn, are not dissolved or oxidized by the anodic treatment; consequently, it is expected that they would remain in the oxide coating. On the other hand, constituents such as $FeAl_3$ and Mg_2Si should be dissolved or oxidized; therefore, they should not be present in the coating. These constituents are sometimes found in the oxide coatings as shown in Figs. 13, 16 and 19. Evidently, these constituents were cut off from electrical contact with the matrix before they could be dissolved or oxidized by the anodic treatment. The presence of particles of constituents in the oxide coatings is responsible for the differences in transparency, color and uniformity of appearance of oxide coatings encountered under some conditions of anodic treatments.

Further examples of the microstructure of anodic coatings are illustrated by Figs. 18 and 19. The first shows the characteristic microstructure of a polished and etched surface section of a wrought aluminum-magnesium-zinc alloy (Fig. 18) which was prepared in such a manner as to produce a very coarse structure. The second micrograph (Fig. 19) shows the structure of a thin section of an anodic coating formed on the same alloy by treatment in a sulphuric acid electrolyte. The microstructure as revealed by light transmitted through the oxide coating shows the same type of constituent and dendritic coring as the original material from which the oxide coating was formed. In contrast, examinations of thin sections of the oxide coating on high purity aluminum samples show no evidence of such microstructural conditions. It is evident, therefore, that the microstructural features shown in Fig. 19 are responsible for differences in transparency of the oxide coating and for the surface pattern which can be observed when the sample is examined visually.

From this outline of methods, it is evident that several are now available for use in further study of the effects of the anodic oxidation process on the characteristics of anodic coatings and the aluminum interface.

Oxidation Characteristics of Aluminum Alloys

It has been found that the anodic oxidation characteristics of an aluminum alloy are influenced by alloying constituents which are in solid solution, by constituents which are rapidly dissolved or oxidized by the anodic treatment and by constituents which are not appreciably dissolved or oxidized.

The alloying constituents which form solid solutions with aluminum are principally copper, magnesium, silicon and zinc. When these constituents are uniformly dispersed in solid solution in the aluminum, a uniform oxide coating is obtained similar to that in the case of a pure metal. On the other

Fig. 9. Al-Si Alloy

Fig. 10. Al-Fe Alloy

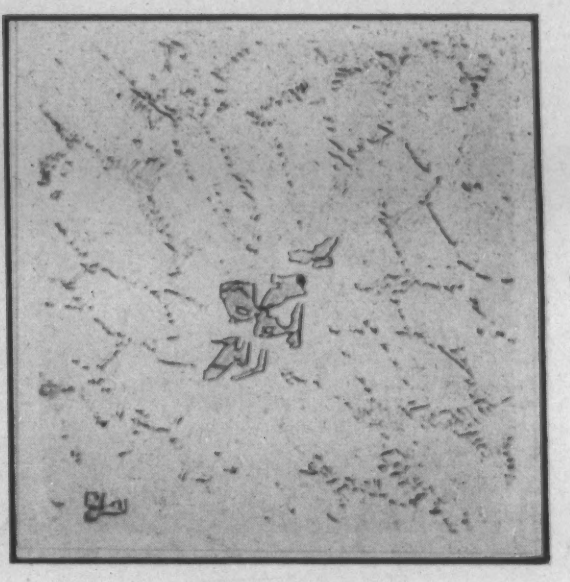


Fig. 11. Al-Mn Alloy

These Three Micrographs Show the Microstructures of the Surfaces of the Three Alloys Noted. The Constituents are Si, $FeAl_3$ and Al-Mn in the order given. Reflected light, vertical illumination. 500X.

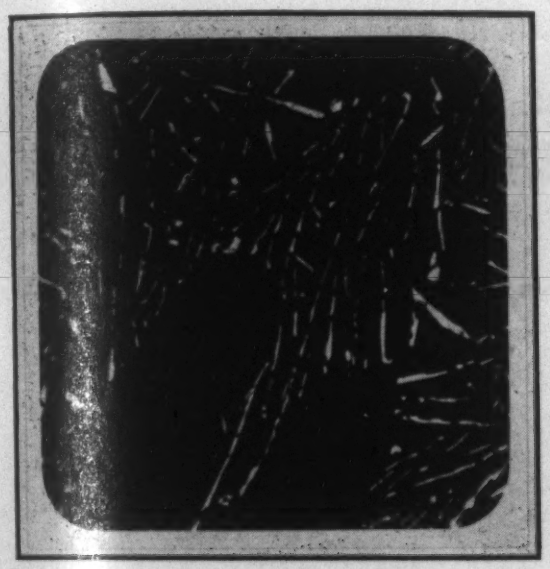


Fig. 12. Al-Si Alloy

Fig. 13. Al-Fe Alloy

Fig. 14. Al-Mn Alloy

These Micrographs Show the Same Constituents in the Oxide Coatings of the Three Alloys as they Appeared in Thin Sections of the Oxide Coatings when they were Examined with Vertical Reflected Light. 500X.

Fig. 15. Al-Si Alloy

Fig. 16. Al-Fe Alloy

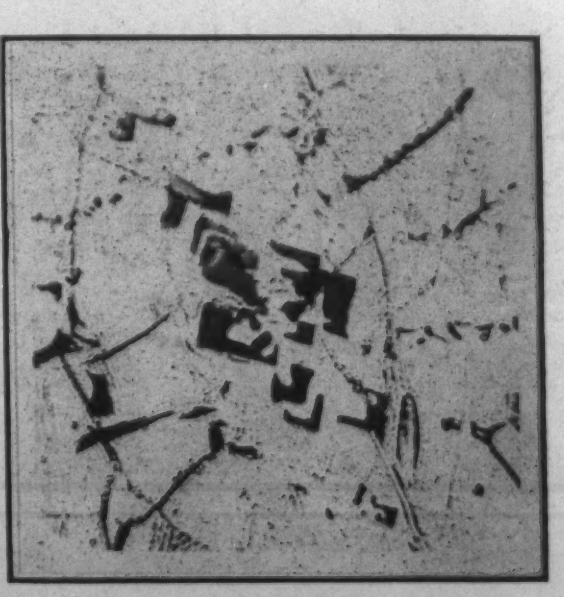


Fig. 17. Al-Mn Alloy

These Micrographs Show the Constituents in the Oxide Coatings of the Same Alloys as they Appeared in Thin Sections of the Oxide Coatings when Examined with Transmitted Light. 500X.

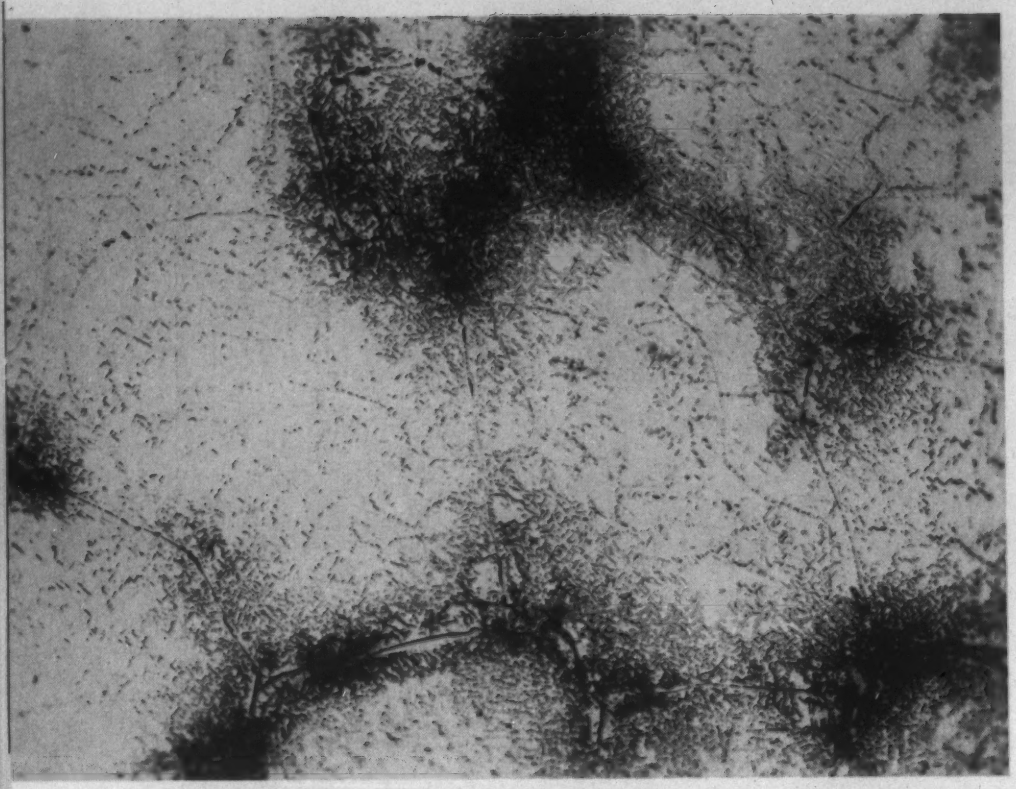


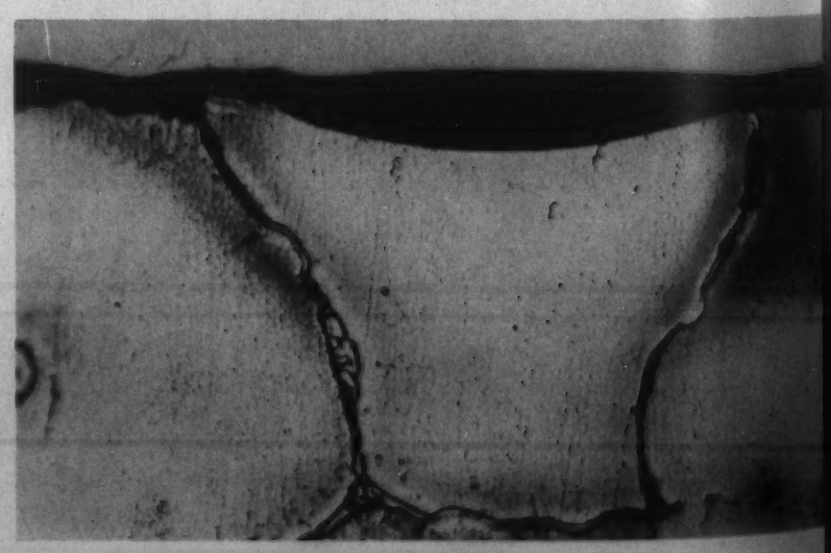
Fig. 18. This Micrograph Shows the Typical Microstructure of an Al-Mg-Zn alloy. This is a surface section; it shows the constituent network and the dendritic coring. Reflected light, vertical illumination. Etch: ½% HF. 100X.

Fig. 19. This is a Micrograph of a Thin Section of the Anodic Coating from the Alloy Shown in Fig. 18 as it Appeared when Examined by Light Transmitted through the Oxide Coating. The microstructure of the oxide coating is similar to that of the surface of the alloy. 100X.

hand, cast aluminum alloys because of their manner of solidification are not homogeneous throughout. This is a result of selective freezing which occurs over a temperature range in alloys. The freezing of an alloy begins with the formation of dendrites that do not have the same composition as the liquid metal but which are richer in the element whose addition to the alloy would raise its freezing point. Under these conditions of solidification a casting develops a dendritic structure. The grain boundaries and dendrite arms contain a network of eutectic composition and are bordered by a zone of solid solution coring which is rich in the alloying elements. In view of such microstructural differences, it is to be expected that different regions of the cast grains would have different oxidation characteristics. This is illustrated by the microstructure shown in Fig. 20. The micrograph shows the structure of an "as cast" aluminum alloy containing 4 per cent copper which has been oxidized in an electrolyte containing 15 per cent sulphuric acid. From the micrograph, it can be observed that the electrolyte attacked the eutectic network along the grain boundaries more rapidly than the alloy matrix. This network was comprised chiefly of the constituent $CuAl_2$. Moreover, the oxide coating on the surface of the sample appears to vary in thickness in relation to the concentration of copper in solid solution in the cored zone. As would be expected, the oxide coating was thinnest at the place where the copper content was the greatest.

From studies of cast samples containing various micro-constituents it appears that cast alloys which have a network of βAl-Mg, Al-Cu-Mg, Al-Cu-Mn, $MgZn_2$, Al-Cu-Ni, Ni-Al_3, αAl-Cu-Fe, βAl-Cu-Fe should have oxidation characteristics similar to those

Fig. 20. This Shows the Rough and Irregular Oxide Coating on an "as cast" 195 alloy (Al-Cu) Sample. The sulphuric acid electrolyte attacked the $CuAl_2$ network preferentially and produced a surface coating of varying thickness because of the solid solution coring within the grains. Reflected light, vertical illumination. Etch: HF-HCl-HNO_3. 500X.



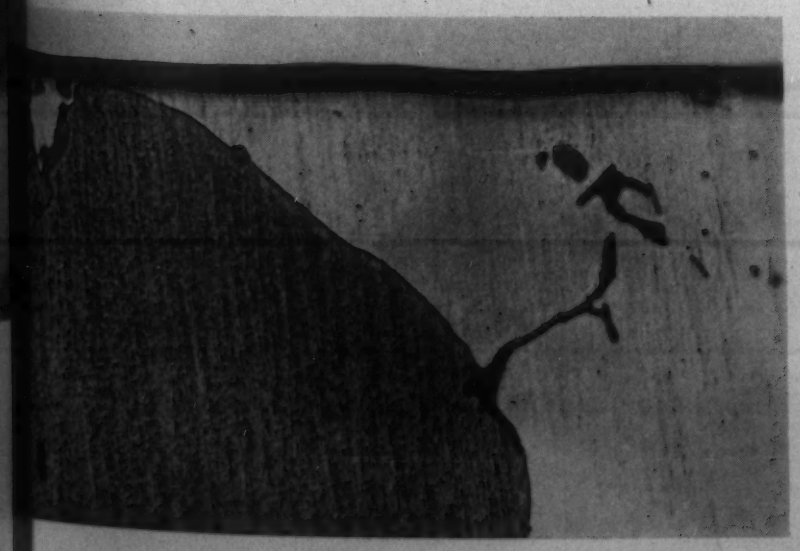
of an alloy containing a network of $CuAl_2$. In such alloys, the results of metallographic work indicate that the constituent network would be dissolved or oxidized in preference to the matrix and that thin rough coatings would result.

If, however, the sample shown in Fig. 20 is given a solution heat treatment to dissolve the $CuAl_2$ in the eutectic network and to produce a uniform distribution of the copper in solid solution within the grains and is quenched, the oxidation characteristics of the sample are changed substantially. The alloy in the heat-treated condition (Fig. 21) develops an oxide coating similar to that obtained on pure aluminum. This anodic coating is uniform in thickness and does not penetrate particularly along the grain boundaries. On casting alloys which contain the constituents listed in amounts which can be dissolved substantially by solution heat treatment, the oxidation characteristics can be improved by heat treatment.

Color of the Anodic Coating

Another point of some importance in connection with the oxidation characteristics of aluminum alloys is the color of the anodic coating. The color of the oxide coating is related to the alloy and the oxidation characteristics of the constituents of the alloy. Alloying additions of copper, magnesium, silicon, manganese and chromium are apt to cause a coloring of the oxide coating. Copper in solid solution in certain amounts gives the anodic coating a decidedly golden color. This color results from the adsorption by the oxide coating of oxidation products from the copper which was in solid solution. In addition to affecting the appearance, such adsorbed oxidation products probably affect other characteristics of the oxide coating such as hardness and porosity. Magnesium silicide imparts a bluish metallic tint to the oxide; manganese gives a brown tint; chromium produces yellow tinted coatings.

Fig. 21. This Shows the Smooth Uniform Oxide Coating on the Same Alloy when the Sample was Given a Solution Heat Treatment Prior to Anodic Treatment. This treatment dissolved the $CuAl_2$ and eliminated the coring. Reflected light, vertical illumination. Etch: HF-HCl-HNO_3. 500X.



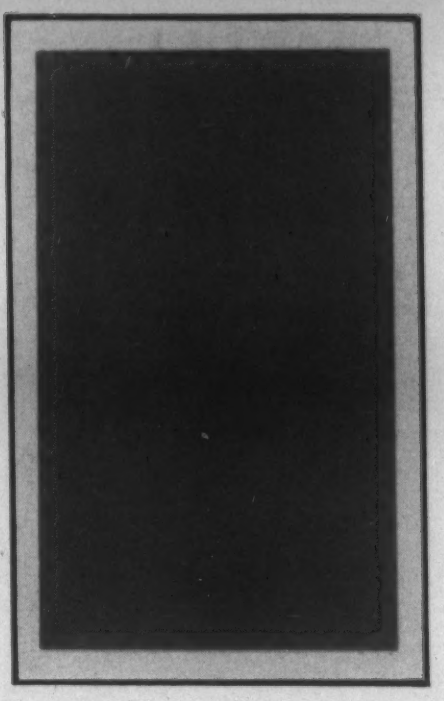


Fig. 22. This Photograph Shows the Color of the Anodic Coating on Al-Si Alloy Sheet (0.7% Si) which was Oxidized in the Annealed Temper.

Fig. 23. This Shows the Color of the Anodic Coating on the Same Sample when Oxidized in the Heat-Treated Temper.

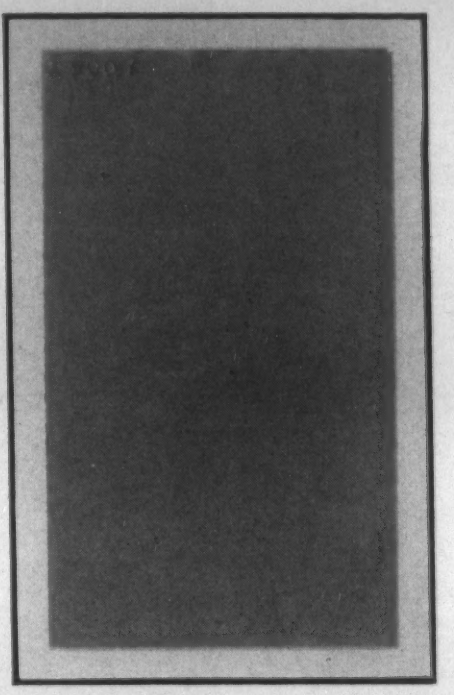


Fig. 24. This Photograph Shows the Color of the Anodic Coating on 51S-O Sheet (annealed).

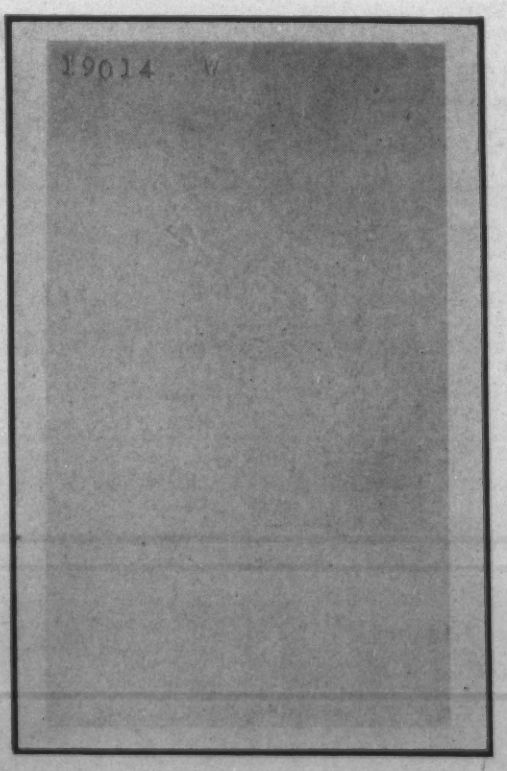


Fig. 25. This Shows the Color of the Anodic Coating on 51S-W Sheet (heat treated).

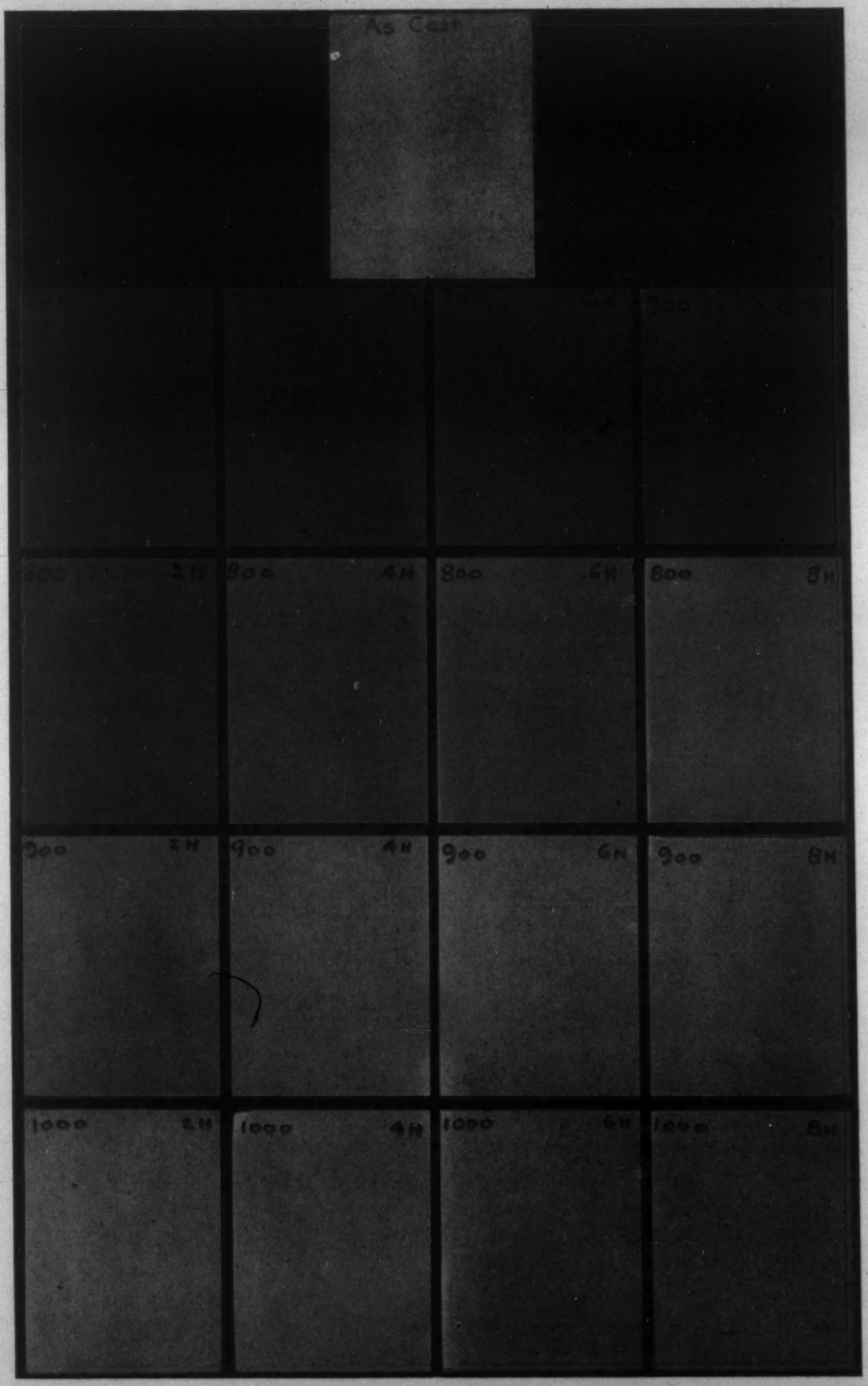


Fig. 26. This Photograph Shows the Changes in the color of Anodically Coated 5 per cent Silicon Alloy Cast Samples Accomplished by Various Thermal Treatments. The changes in microstructure are shown in Figs. 27 to 31 inclusive.

Fig. 27. Shows Microstructure of 5 per cent Silicon Alloy in "As Cast" Condition. 500X.

Fig. 28. Shows Microstructu after Same Alloy was Hea for 2 hrs. at 700 deg. 500X.

These colored oxide coatings are not as transparent as the coatings on pure aluminum because of the presence of the colored oxidation products. It is possible, however, in some cases to change the color of the oxidized samples by suitable thermal treatments prior to oxidation. Examples of the effects of thermal treatments on the color of anodically coated samples of an aluminum-silicon and of an aluminum-magnesium-silicide alloy are illustrated in Figs. 22 to 25 inclusive. The photographs show that the alloys have a dull dark oxide coating when they are oxidized in the annealed temper and a light metallic oxide coating when oxidized in the heat-treated temper.

Aluminum-silicon alloys under some conditions form oxide coatings which do not have a metallic luster and which have a brown to black color. This condition is readily explainable because elemental silicon is not dissolved or oxidized in the anodic process. The color of these coatings is a function of the amount and size of the particles of elemental silicon particles, large enough to be visible under the microscope, are dispersed throughout the oxide coating. Examples of the effect of different dispersions of elemental silicon particles in cast samples of an alloy containing 5 per cent silicon are shown in Fig. 26. The "as cast" sample has a light oxide coating because the alloy contains no small particles of elemental silicon as shown by the microstructure of the sample in Fig. 27. The other samples in Fig. 26 show the color of the oxide coatings on cast samples of the same alloy after thermal treatment for various times at 700 to 1000 deg. F. The low temperature treatments cause precipitation of fine elemental silicon particles as shown in Figs. 28 to 31 inclusive. The presence of these fine particles of silicon in the oxide coatings of the samples is responsible for the various shades of color. The sample which was heated at 1000 deg. F. has only a small amount of precipitated silicon; therefore, the color of the oxide coating was almost the same as that of the "as cast" sample.

Conclusions

The preceding descriptive material has dealt with the effects of electrolytic oxidation on the color and uniformity of appearance of anodic coatings on aluminum alloys containing a variety of constituents. It has been shown by several methods of metallographic examination that the size and distribution of the micro-constituents may have important effects on the oxidation characteristics. The tendency of some anodically oxidized aluminum alloy samples to develop a streaked appearance during the treatment is influenced by the amount, size, distribution and oxidation characteristics of the micro-constituents. Because of these facts, some aluminum alloys are found to be more suitable for anodic oxidation treatment than others.

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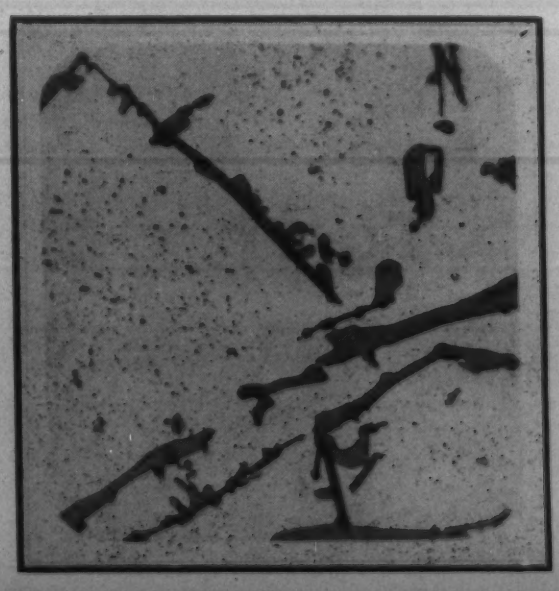
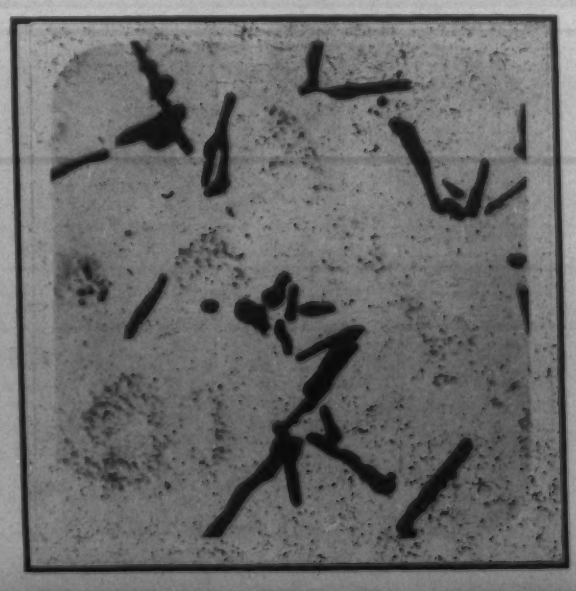
Fig. 29 Shows Microstructure after Same Alloy was Heated for 2 hrs. at 800 deg. F. 500X.

Fig. 30 Shows Microstructure after Same Alloy was Heated for 2 hrs. at 900 deg. F. 500X.

Fig. 31 Shows Microstructure after Same Alloy was Heated for 2 hrs. at 1000 deg. F. 500X.





EDITORIALS (*Continued from page 163*)

effort by representatives of both the large and small operating companies to exchange helpful or critical information. The net result could not help but be eminently beneficial and progressive—an augury of still better results from open-hearth operations in the future.—E. F. C.

The Mineral Sanction

Professor R. S. Lewis of the University of Utah, in the third annual Reynolds Memorial Lecture, delivered in January, discusses a proposal made by General Smuts to the League of Nations as a mode of restraining such actions as that of Japan in invading Manchuria and later over-running China. Italy's behavior in regard to Ethiopia and that of both Italy and Germany in respect to Spain would fall into the same category.

Smuts' suggestion was that, when the League of Nations unanimously appraise the actions of a country as those of an aggressor against another, the other nations should declare an embargo on the export of mineral products of any kind to the offending nation. This "mineral sanction" could be adopted by countries outside the League, just as the Kellogg-Briand pact was adopted. It is argued that it would require no naval blockade, nor would it interfere with the supply of foodstuffs, medicines, and the like for the misled, relatively innocent, populace of the countries ruled by ruthless dictators.

Lewis gives convincing evidence of the dependence of industrial life on mineral products. He points out that Hitler has openly admitted that the Spanish war was fought primarily to secure iron ore for Germany.

Whatever one may think about actively providing munitions or raw materials therefore to friendly countries whom we can trust to use them for defense if they are set upon, the prospect of merely refusing to supply materials for munitions to those who, in spite of fair words, have carried on foul deeds of aggression and whom, in consequence, we do not trust, will find fewer opponents. A pacifist may feel that it is not just the thing to give a revolver to a policeman, but at least he should like even less to give the revolver to the maniac from whom the policeman is trying to guard his charges.

At any rate, Lewis' discussion is eloquent proof of the vital role played by mineral and metallurgical materials, both in peace and war.—H.W.G.

A Chuckle

Tough on the Alloy

One of our metallurgical contemporaries prints a news release stating that a certain firm has been licensed to founder a trade named alloy. According to the definitions in our dictionary this would be rather tough treatment to a pet alloy.—H. W. G.

Flood-Lubricated Bearings (from page 169)

plications of the flood-lubricated sleeve bearing is for rolling aluminum foil. One foil manufacturer, for example, replaced his original old fashioned plain metal bearings with Morgoil bearings, because the old bearings definitely limited the speed of the mill. Production was stepped up 300 per cent, and this company is now finishing 0.0003-in. aluminum foil in strips 27 in. wide at high speed, only on mills with Morgoil-equipped rolls.

Table of Power Savings Recorded on 12-in. Continuous Strip Mill when Old-Fashioned Bearings were Replaced with Morgoils on Last 6 Stands

Size of Strip	Kw.-Hr. per Ton for Stands 7-12 Morgoil	Ordinary	Per Cent Saving
2 in. x 0.040 in.	47.7	116	59
2 in. x 0.030 in.	72.1	180	60
2⅜ in. x 0.064 in.	35.2	89	60.5
1¼ in. x 0.030 in.	99.5	233	57
3 1/16 in. x 0.048 in.	41.1	93.6	56.1
2 1/16 in. x 0.036 in.	65.2	166.8	60.9
1¼ in. x 0.040 in.	58.4	136	57.1
3¼ in. x 0.048 in.	39.8	93.6	57.5
3 5/16 in. x 0.070 in.	29.8	73	59.2
3⅛ in. x 0.064 in.	32.3	71	54.5

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